Shock mitigating seat single impact program

Chantal AuCoin
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Prepared by:
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PWGSC Contract Number: W8482-083790/001/ML

Contract Scientific Authority: Liam Gannon, Defence Scientist, 902-426-3100 x130

Defence Research and Development Canada

Contract Report
DRDC-RDDC-2014-C89
April 2014

Naval Engineering Test Establishment
9401 Wanklyn
LaSalle QC H8R 1Z2

2711-3830- ZT4110-R (NETE)

24 April 2014

DRDC Atlantic
Defence Headquarters
101 Colonel by Drive
Ottawa, ON K1A 0K2

SHOCK MITIGATING SEAT SINGLE IMPACT PROGRAM

References: A. Task ZT4110-R Approved 21 September 2011
B. 2711 (NETE CS) ZT4110-R, Letter report dated 23 April 2014 (enclosed)
C. Deliverable Acceptance Form (enclosed)

1. Under Reference A, NETE was tasked to deliver Reference B, which is forwarded for your acceptance. The NETE Management Contract with Weir Canada, Inc., allows for 30 calendar days for DND's final review and acceptance of deliverables. Consequently, you have until 26 May 2014 to forward your written acceptance of Reference B using Reference C, enclosed for your convenience.

2. It is important to note that the written assessment provided as part of Reference C will also be used at the end of the FY to determine a Performance Incentive Fee (PIF). The Contractor will be awarded a PIF based on the average of all assessments received. Without your input, the Contractor will be assigned the same assessment provided by CO NETE for this deliverable, which may not reflect the true quality of Reference B. Therefore, it is requested that the "Deliverable Acceptance Form" attached be completed and returned via RDIMS or email, if possible, upon receipt. If you have any questions, please contact Colin Smith at (514) 366-4310.

Chantal AuCoin
Commander
Commanding Officer
(514) 366-4310, Ext. 307

NAVAL ENGINEERING TEST ESTABLISHMENT (NETE)
CENTRE D'ESSAIS TECHNIQUES (MER)
9401 Wanklyn, LaSalle, Québec H8R 1Z2

DELIVERABLE ACCEPTANCE FORM

Date: 24 April 2014
From: Project Manager NETE Task #ZT4110-R: DRDC Atlantic

To: Cdr Chantal AuCoin (Commanding Officer NETE)

Return Form: RDIMS or email (nete.taskadmin@intern.mil.ca) or Fax 514-366-8879

References: A. Task ZT4110-R, Approved 21 September 2011
B. 2711 (NETE CS) SHOCK MITIGATING SEAT SINGLE IMPACT PROGRAM

As Project Manager for NETE Task ZT4110-R, I accept Reference B as meeting the requirement stated in the task description:

☐ YES or ☐ NO

(Please Check Box)

My assessment of the quality of Reference B is:

☐ Excellent ☐ Good ☐ Satisfactory ☐ Needs Improvement ☐ Unsatisfactory

Comments:

Project Manager or Technical OPI: ____________________ Date Completed: ______________

* It is important to note that the "Deliverable Acceptance Form" will be used at the end of each Quarter as well as at the end of the FY to determine a Performance Incentive Fee (PIF). As such, it is requested that this form be completed and returned via RDIMS or email, if possible, upon receipt.

Weir Canada, Inc.

Weir Marine Engineering
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Excellent
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23 April 2014

Department of National Defence
Naval Engineering Test Establishment
9401 Wanklyn St.
LaSalle, QC H8R 1Z2

Att.: Cdr C.G. AuCoin
Commanding Officer, NETE

Re.: PWGSC Contract No. W8482-083790/001/ML
Submission of Deliverables
Annex A, Section 4, Paragraph 43

Cdr AuCoin:

The attached letter report entitled "Shock Mitigating Seat Single Impact Test Program" dated 23 April 2014 has been prepared under Task ZT4110-R and in accordance with the referenced contractual terms, one copy of the document is being submitted to you for review and formal acceptance by the DND Project Manager (DRDC Atlantic) of record.

In the event that no feedback or comments are received within 30 calendar days of the date of this letter, this deliverable will be considered acceptable.

Please let me know if any questions arise.

Yours truly,

for Serge Lamirande
Site Manager, NETE

SL/rr

Attach.

NOTICE

This documentation has been reviewed by the technical authority and does not contain controlled goods.

AVIS

Cette documentation a été révisée par l'Autorité technique et ne contient pas de marchandises contrôlées.

2711 (NETE CS) ZT4110-R
23 April 2014

SHOCK MITIGATING SEAT SINGLE IMPACT TEST PROGRAM

References: A. NETE Task ZT4110-R, approved 21 September 2011
B. NETE Task ZT4110-R, TCR Rev.02, approved 11 April 2013
C. Shock Mitigation Seat Test and Evaluation, presented at the Royal Institute of Naval Architects Human Factors in Ship Design and Operation Conference, 16 to 17 November 2011
D. HexWeb® Honeycomb Energy Absorption Systems, Design Data, dated March 2005
E. Single Impact Testing and Analysis of Shock Mitigating Seats, DRDC 2900-2, dated July 2 2013
F. Drop Testing of Shock Mitigating Seats for High Speed Craft – Phases 3 & 4, DRDC Scientific Letter

AIM

1. This letter report describes the progression of a task aimed at conducting a series of single impact shock tests on a selection of shock mitigating seats that are or could be used on board Canadian Armed Forces (CAF) high speed craft (HSC).

INTRODUCTION

2. At References A and B, the Naval Engineering Test Establishment (NETE) was tasked by Defence Research and Development Canada (Atlantic) (DRDC[A]) under Task ZT4110-R, to conduct a series of single impact shock tests on a selection of Commercial-off-the-Shelf (COTS) shock mitigating seats. The seats had been acquired by DRDC(A) in support of a Research and Development (R&D) initiative supported by Canadian Special Operations Force Command (CANSOFCOM). The R&D initiative is aimed at reducing the risk of acute and chronic injury to personnel serving in small high speed military crafts by seeking to improve the state of the art for modeling, simulation, testing, and evaluation of shock mitigation seat technologies. A description of the R&D initiative and related information on human factor issues, the full test and evaluation program, seat suspension configurations, etc. is provided at Reference C and this letter report has extracted relevant background information from its contents.

3. The test and evaluation portion of the R&D initiative comprises the following:

a. benchmarking contemporary technologies;

b. developing test capabilities and test protocols;

c. developing math models and simulation codes;

d. validating models and codes using data derived from the test protocols; and

e. documenting results and recommendations.

4. Initial benchmarking of contemporary technologies was conducted between late 2010 and mid 2011 with the acquisition of 12 models of COTS shock mitigating seats from three North American manufacturers and one European manufacturer.

5. This report describes the work done to date in developing test capabilities and protocols, and includes the evolution of the test protocol from the initial concept to the final version.

6. In addition to supporting the R&D, initiative the data collected will provide the technical input required to enable the acquisition of the most suitable shock mitigating seat for current and future HSC.

DISCUSSION

Seats Acquired for Testing

7. Initially, the seats acquired for testing and evaluation were as follows:

a. Shockwave Seats (Division of Professional Components Ltd.):

(1) Folding Combat Seat – Model SW-917;

(2) Jockey Pod Seat – Model S1;

(3) Folding Assaulter Seat – Front Mounted (FMAS); and

(4) Folding Assaulter Seat – Rear Mounted (RMAS).

b. Coastal Dynamics Group Ltd. (SHOXS):

(1) Folding Combat Seat – Model 4800 with Semi-active Control;

(2) Folding Combat Seat – Model 4800;

(3) Folding Combat Seat – Model 6500;

(4) Jockey Pod Seat – Model 5500; and

(5) Folding Assaulter Seat (Front Mount) – Model 5100.

c. STIDD Systems Inc.:

(1) Folding Combat Seat – Model 800V35.

d. Ullman Dynamics:

(1) Jockey Seat – Compact; and

(2) Combat Seat – Atlantic.

8. The initial two phases of the final seat test program were complete between April and May 2013 and in the time between the initial acquisition and completion of these tests, another candidate

seat had been developed by Zodiac Hurricane Technologies Inc. Because of this, the client requested that a sample of this seat should be included in the test program. Also, the manufacturers of Shockwave and SHOXS seats stated that their seats had also undergone minor upgrades and samples of their current jockey style seats were acquired. The new seats from Shockwave, SHOXS and Zodiac, were tested during the third and fourth phases of the final test program and these were conducted between December 2013 and January 2014.

9. The following figures show images each of the seats extracted from the manufacturer's web pages and in most cases show the general configuration of the seat models acquired. The images serve to show the general differences between seats but do not show the seats as acquired. Any differences between the images and the acquired seats are superficial and typically due to seat model updates or show seats with optional equipment installed.

10. The selected seats fall into three general seating categories and, with one exception, two of the suspension seat configurations that are available currently. The first category is the combat seat that typically offers the occupant a padded seat and back (with or without an optional headrest, padded armrests with hand grips and a footrest). In the stowed position the seat and footrest are folded flat and this allows the occupant the option of standing by personal preference or when needed by operational requirements (See Photograph 1). The top of the folded seat pad can also provide a buttock rest that enables the occupant to slightly bend their legs and combine the shock mitigating functions of the seat with their ability to absorb shock using their major muscle groups. On CAF HSC, this style seat is normally used by boat cox'ns and navigators.

Photograph 1(a) - Shockwave Folding Combat Seat

Photograph 1(b) - STIDD Folding Combat Seat

Photograph 1(c) - SHOXS 4800 Combat Seat

Photograph 1(d) - SHOXS 6500 Combat Seat

Photograph 1 - Combat Style Seats

11. Second category seats are jockey seats (see Photograph 2) where the occupant sits, as on a horse, with both feet supported on seat mounted stirrups and foot pads while holding onto an integral front hand grip. Within the selected seats there were three sub-groups of jockey seats. The first sub-group are jockey pod seats that do not fold and have storage compartments under the seat cushions. The second sub-group are folding jockey seats that have a fixed deck-mounted base and a seat cushion that is mounted to an articulated support structure, hand hold and foot rest that fold-up to provide additional clear deck space. The final sub-group are also folding jockey seats, but without a deck-mounted base. These seats mount to the back of a deck-mounted, jockey pod seat and are folded when not required to provide additional deck space. On CAF HSC, this style seat is normally used by assaulters or boarding parties.

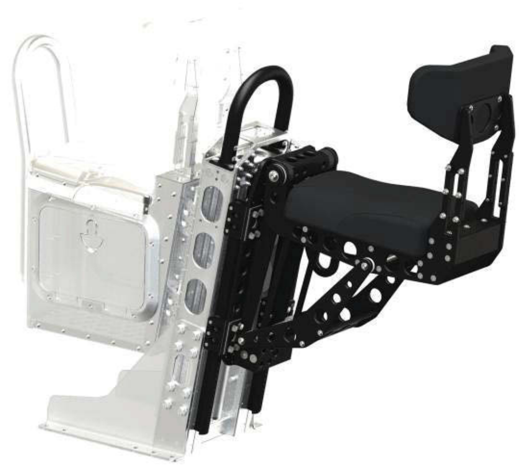
12. Third category seats are represented by the smaller of the Ullman seats (see Photograph 3) and it is designed to suit the more upright near standing position described above for the folded combat seat. On this style of seat, the occupant sits near upright with legs slightly bent and feet resting either on the deck or on seat-base mounted footrests. These seats are designed to be used in rows where the occupant uses a hand grip mounted on the seat in front. The front seat of the row has a hand grip mounted to the front of its base.

13. The Ullman Atlantic is a hybrid of a non-folding combat seat and Ullman Compact seat. It has folding arms and footrests, as well as a thigh bolster.

Photograph 2(a) - Shockwave S1 Jockey Pod and FMAS

Photograph 2(b) - Shockwave RMAS

Photograph 2(c) - SHOXS Model 5500 Jockey Pod Seat



Photograph 2(d) - SHOXS Folding Assaulter Seat – Model 5100

Photograph 2(e) - Zodiac MilPro Jockey Pod Seat

Photograph 2 - Jockey Pod Seats

Photograph 3(a) - Ullman Compact Jockey Seat

Photograph 3(b) - Ullman Atlantic Combat Seat

Photograph 3 - Ullman Seats

Seat Suspension Systems

14. To avoid confusion this report uses the suspension seat terminology described in Reference C to describe the suspension seat configurations employed by the 11 models of seats listed above and these are:

a. Passive;

b. Adaptive; and

c. Semi-active.

15. Passive Suspension. A passive suspension system is the simplest suspension system and typically employs springs, pneumatic or hydraulic dampers or a combination of these to decouple the seat occupant and moving portion of the seat from the fixed seat base and boat motions. These are purely mechanical systems, normally without user adjustment capability, that do not have any electrical and electronic components. The lack of adjustment can be considered to be the major disadvantage of this system since the shock attenuation cannot be changed to suit varying sea states and differences in occupant mass. However, it can also be thought of as an advantage since there is a potential for incorrect seat adjustments to be made that can potentially compromise the damping capabilities of the suspension system as environmental conditions or occupants change. From the seats acquired for testing, the SHOXS Models 4800 (2 off), 6500, 5100, 5500 and the Ullman Compact Jockey seats were fitted with passive suspension systems (Note that the SHOXS seats can be adjusted, but this is not recommended and should be done by the manufacturer).

16. Adaptive Suspension. Adaptive suspension systems are similar to their equivalent passive suspension systems with the addition of a means of adjusting the stiffness of the suspension system.

Typically, the adjustment is made by increasing or decreasing in the damper's internal pressure or coil spring pre-tension. Typically, the adjustments are made at the start of missions to suit the expected environmental conditions and occupant, and are not adjusted as the mission continues. These systems also do not have electrical or electronic components. Advantages and disadvantages are much like those of passive suspension systems. It is advantageous to be able to adjust the seat suspension to suit the current or expected conditions or occupant, but the disadvantage is that the potential exists for any specific set-up to be detrimental should the conditions or occupant change. The Shockwave, STIDD and Ullman Atlantic seats are equipped with adaptive suspension systems.

17. Semi-Active Suspension. Semi-active suspension systems also use passive suspension elements, but complexity is increased with the addition of a means of continuously controlling the motion damping. The control system requires electrical power and a means of monitoring vessel and seat motions. One of the SHOXS Model 4800 seats was equipped with a semi-active suspension system.

Seat Testing Program at NETE

18. HSC motion in a seaway and the resulting effects of the shock and vibration on the occupants has been studied extensively by governments, commercial operators and organizations and a 2002 European Union (EU) Physical Agents Directive[1] has imposed limits on the daily exposure of workers to the risks arising from Whole-Body-Vibration (WBV). A further study[2] has shown that the occupants of HSC can exceed the EU WBV daily exposure limit within minutes when transiting under severe sea conditions and this has had the effect of increasing the research and development of improved hull forms, HSC ergonomics and shock and vibration mitigation systems.

19. For the seat test program, it would be necessary to develop a series of mechanical static and dynamic tests that would be repeatable and would, to the greatest extent possible, represent an acceleration/time profile that would be an acceptable representation of a complex dynamic process. It was accepted that one acceleration/time profile could not be expected to represent the slam events experienced by all types and sizes of HSC operating under all sea conditions and at all speeds and loading conditions, but would provide a baseline.

20. Figure 1 shows the vertical accelerations/time profile that was to be the basis for the seat testing program with the three distinct zones of a typical HSC slam event identified. These zones are; (a) a free-fall zone that occurs when the forward motion of the craft carries it off the crest of a wave; (b) the slam impact as the craft hits the water after free-fall and the deceasing acceleration as the craft settles into the water; and (c) the recovery due to buoyancy and hydrodynamic effects. The period covered by this typical slam event cycle varies depending on sea state, craft speed, direction, etc.

[1] European Union Directive (2002/44/EC) on the health and safety requirements regarding the exposure of workers to the risks arising from physical agents.

[2] Holmes S, Dobbins T, Leamon S, Myers S, Robertson K, King S, (2006), the effects of rigid inflatable boat transits on performance and fatigue. Conference Proceedings: ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue, Panama City, FL, USA

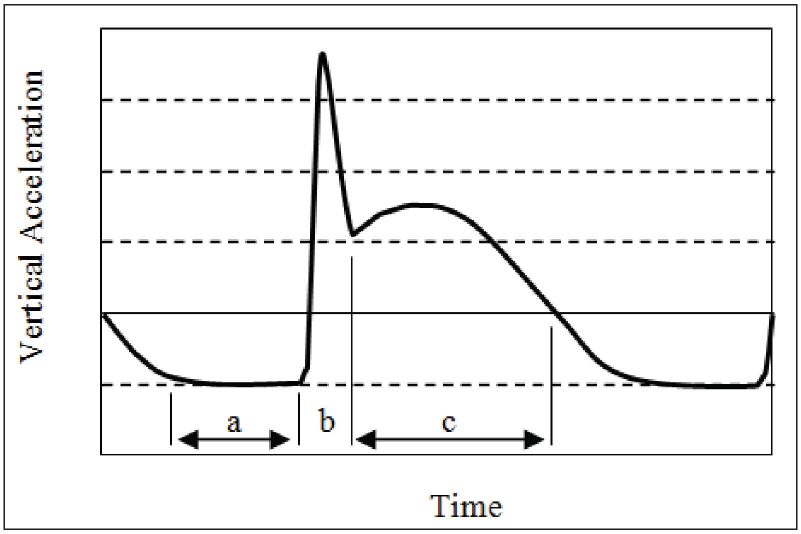


Figure 1 - HSC Slam Event Vertical Acceleration/Time Profile

21. For the first phase of the shock mitigating seat testing program, NETE was requested to investigate the possibility of using their facility's Medium Weight Shock Test Machine (MWSTM), see Figure 2, to generate the peak acceleration/time profiles similar to that shown as Zone (b) in Figure 1 with peak accelerations approximating up to 20 g and half-sine durations of approximately 100 milliseconds (ms). The possibility of replicating Zone (c) profile would also be investigated.

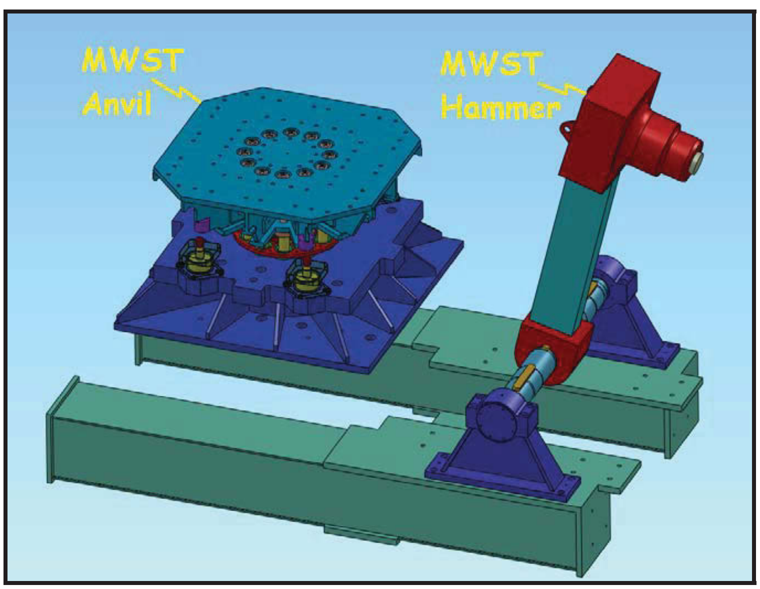


Figure 2 - Illustration of NETE's Medium Weight Shock Test Machine

22. The planned seat test program would test all seats at each of three peak acceleration levels (Zone [b]) between 5 g and 20 g and, if possible, repeat the testing at lower g-levels with an acceleration/time profile similar to Zone (c). It was expected that a data acquisition system would be used for the tests and instrumentation would be installed that would measure accelerations at up

to three axes on the seat base, suspended seat pan and on top of the seat cushion using a standard seat pad accelerometer.

23. During this phase, each seat would be mounted on the machine’s anvil platform and an un-instrumented, semi-articulated, anthropomorphic test manikin would be secured in place with as realistic a posture as possible. The selected manikin would have a mass that would be representative of a 95 percentile seat occupant with full boarding kit (approximately 250 lb).

24. High speed video cameras and specialized analyse software would be used to track multiple points of interest on the rigid and suspended sections of the seats, on the seat cushions to measure compression and on the manikin. This tracking software would be used to develop a velocity profile for the shock event.

25. It was also planned to conduct a limited series of tests using the MWSTM inclined planes to provide data on seats exposed to simultaneous lateral and vertical accelerations. These tests would be performed using only the combat seats.

26. The MWSTM is a hammer and anvil device that is normally used to qualify relatively large pieces of equipment for use on board warships by simulating the high-energy effects of underwater or airborne shock pulses. The machine is typically used for equipment weighing up to 3000 kg and acceleration levels in excess of 200 g. As such, it was recognized that it would be necessary to conduct exploratory tests to define the machine’s lower limitations of peak acceleration/time profiles.

27. It was expected that the slam impact peak acceleration pulse could be easily achieved with relatively small hammer release heights and the challenges would be repeatability and increasing the pulse duration. For this series of tests, the seats would be hard-mounted to the machine’s standard anvil interface structure. To achieve the lower-intensity, longer-duration, recovery phase acceleration pulse, it would be necessary to introduce resilient mounts between the anvil table interface and the seat mounting plate interface (see Figure 3).

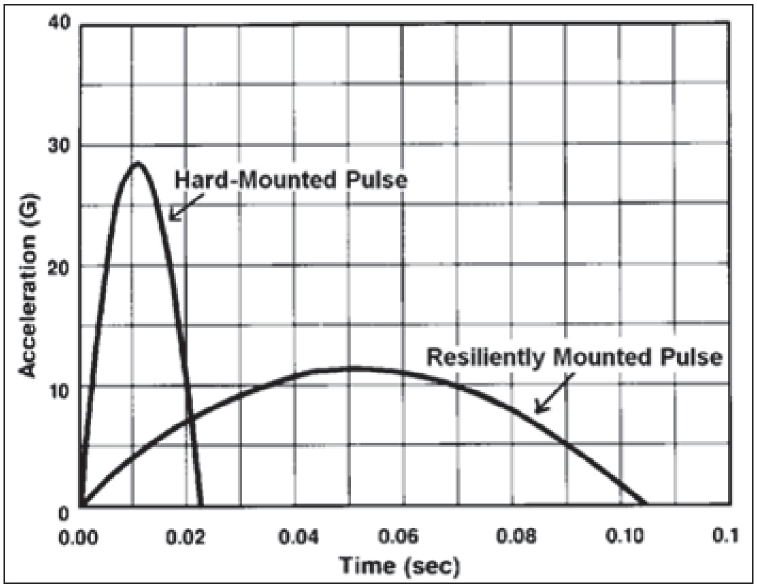


Figure 3 - Pulse Duration Profiles

28. The hard-mounted pulse profile would be adjusted by varying the hammer release height and the pulse duration would be adjusted by attaching a resilient or crushable impact attenuators to the machine's hammer face or to the underside of the anvil. The resiliently-mounted pulse profile would be adjusted by using suitably sized wire rope isolators in one of three configurations; (1) four isolators mounted diagonally from the corners of the interface plates; (2) eight isolators mounted longitudinally, transversely and diagonally; and (3) eight isolators mounted diagonally and stacked. Figure 4 shows diagrammatically the theoretical effect on the pulse duration for each configuration.

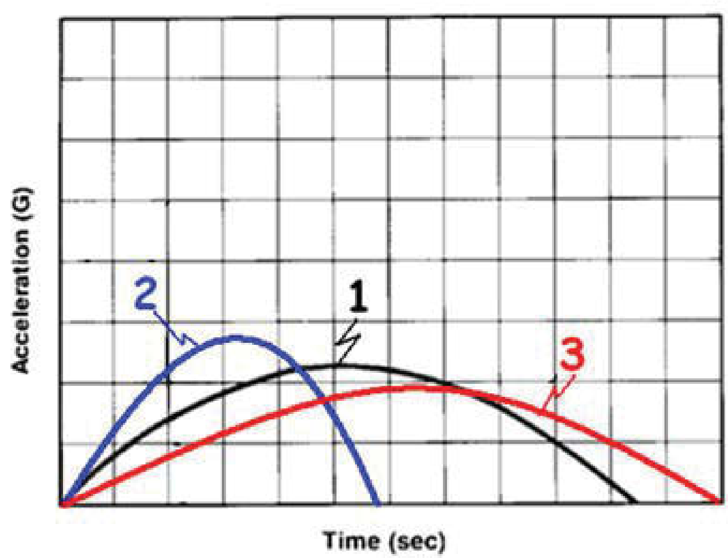


Figure 4 - Resilient Mount Configuration Change on Pulse Profile

29. Prior to starting the exploratory tests, it was necessary to determine the total mass used for testing since seat weights varied for 45 lb to 215 lb and were suitable for either one or two

occupants. To develop test parameters for each configuration was not feasible and it was determined that a mass equivalent to the heaviest dual seat configuration with two manikins with an additional ballast allowance would be used. During testing, the required steel plate ballast weights would be bolted to the MWSTM's seat interface plate (see Table 1).

Table 1 - Test Weight Details

Manufac.	Model / Description	Seats Weight	Seat & Manikin Weight	Required Ballast Weight	Total weight over interface plate
Shock Wave	Special Operation Seats	165 lbs	415 lbs	385 lbs	800 lbs
	Jockey Pod Seat	111 lbs	361 lbs	439 lbs	
	Front & Back Mounted Assault Seats – Dual	215 lbs	715 lbs	85 lbs	
SHOXS	SHOXS 4800	157 lbs	407 lbs	393 lbs	
	SHOXS 6500	140 lbs	390 lbs	410 lbs	
	SHOXS 5500 / 5100 – Dual	130 lbs	580 lbs	220 lbs	
STIDD	Advanced Shock-Mitigating Seat/Bolster, Model 800V53	143 lbs	393 lbs	407 lbs	
Ullman Dynamics	Ullman Atlantic	121 lbs	371 lbs	429 lbs	
	Ullman Jockey Seat Compact	45 lbs	295 lbs	505 lbs	

30. With the total test weight and each test configuration centre of gravity known, it was possible to fabricate a steel dummy load that would be representative of test configurations and would allow exploratory tests to be conducted without damaging the seats and without the interference of the movement of the suspended mass of the seat(s) and manikin(s). Illustrations of the hard-mounted and the Type (2) resilient-mount exploratory set-up are shown in Figure 5.

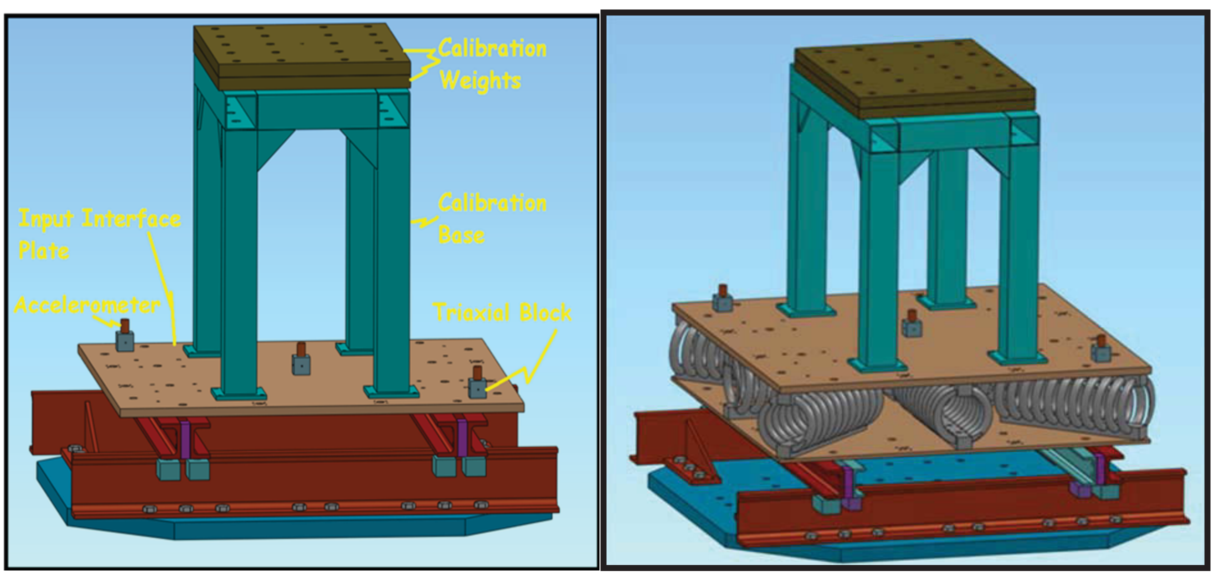


Figure 5 - Illustrations of the Exploratory Test Set-Up
(Hard-Mounted at Left: Resilient Mounted at Right)

31. Exploratory testing commenced with characterising the MWSTM shock impulse magnitude, duration and repeatability at very low hammer heights. Instrumentation used during the

characterisation included high speed cameras to record the events and three single-axis, piezo-resistive accelerometers mounted to the interface plate. Data were collected using a DEWETRON DEWE-571 multi-channel data acquisition system. Data were sampled at 10 kHz and low-pass filtered with a cut-off frequency of 250 Hz.

32. Figure 6 shows a typical acceleration/time plot for the hard-mounted configuration with an allowable machine table travel of 1.5" and a hammer height of 2" and no hammer attenuation. Figure 7 shows the initial pulse in detail showing that the maximum and minimum g-levels were 34.3 g and -23.3 g respectively and the initial impulse duration was a relatively short 5 milliseconds. This series of exploratory tests showed that acceleration levels below 20 g would be difficult to achieve because of the difficulty in accurately positioning the hammer for the necessarily small hammer heights required.

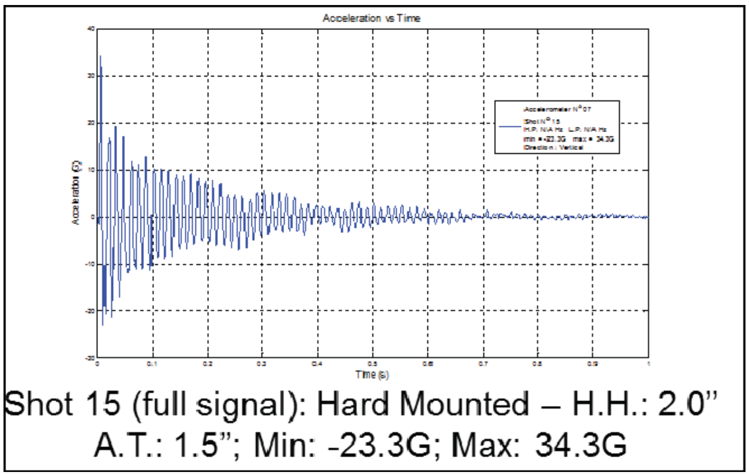


Figure 6 - Typical Hard-Mounted Acceleration/Time Plot

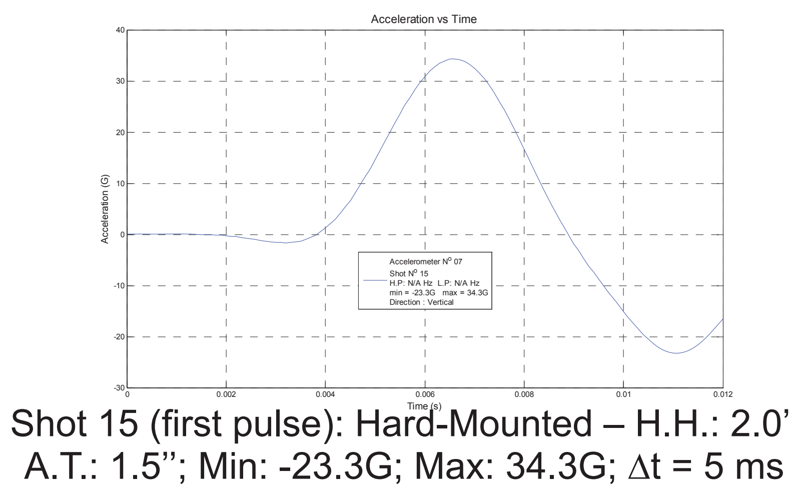
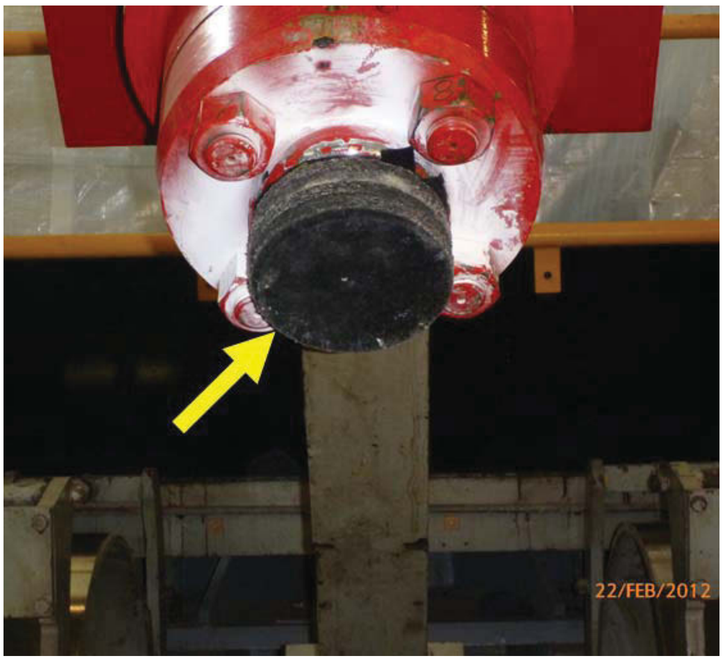


Figure 7 - Typical Initial Pulse Profile

33. Exploratory testing continued with the addition of an impact attenuator placed between the hammer's striking face and anvil's striking face with the intent of reducing the impact magnitude

and increasing the duration of the initial pulse. For the initial tests, a 2” thick stack of nitrile vibration damping pads was attached to the hammer striking face (see Photograph 4). Seven blows were carried out; three with the MWSTM set-up to allow a 1.5” anvil travel and a hammer release height of up to 12” and four with the machine set-up for 3.5” anvil travel and 10” release height. Figures 8 and 9 show the complete accelerometer/time plot for both series at their maximum hammer release heights. Comparing these figures to Figure 6 clearly shows that the attenuator has reduced the initial impact g-levels and the higher magnitude g-levels occur when the anvil contacts the travel stops on the upwards travel and the lower stops on rebound.



Photograph 4 - Hammer Face Attenuator

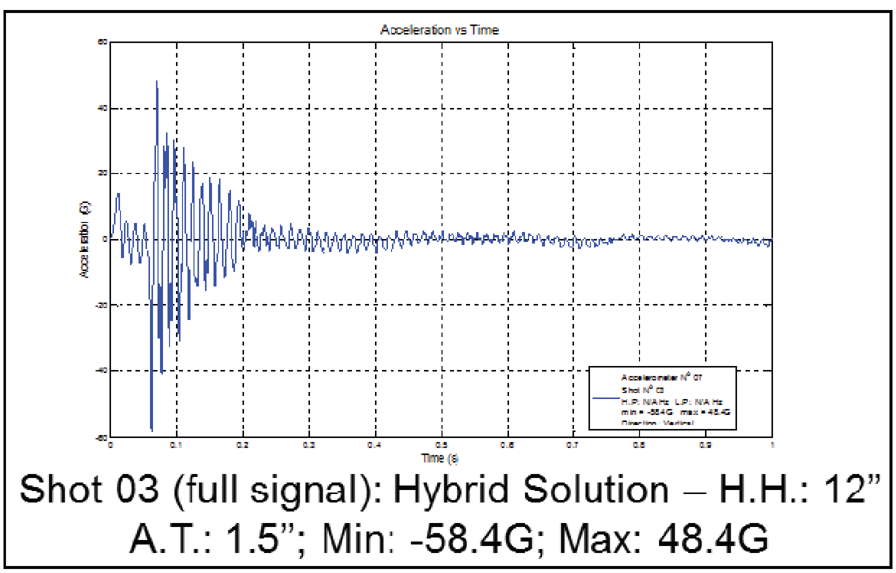
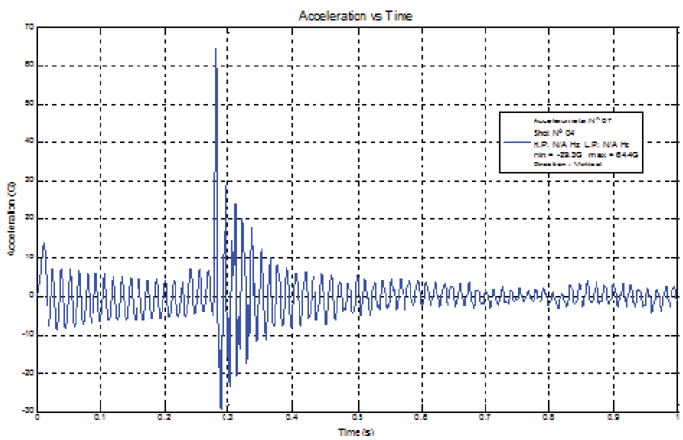


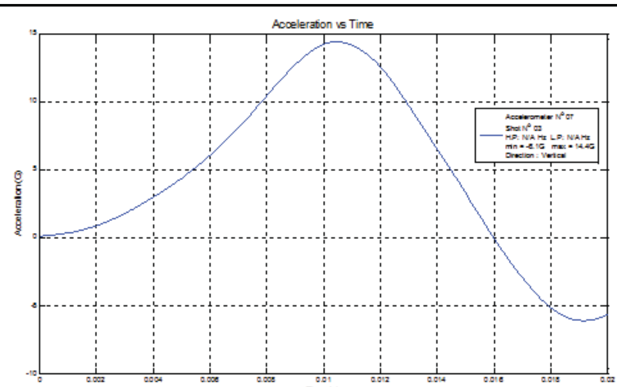
Figure 8 - Acceleration/Time Plot for 1.5” Anvil Travel



Shot 04 (full signal): Hybrid Solution – H.H.: 10”
A.T.: 3.5”; Min: -29.3G; Max: 64.4G

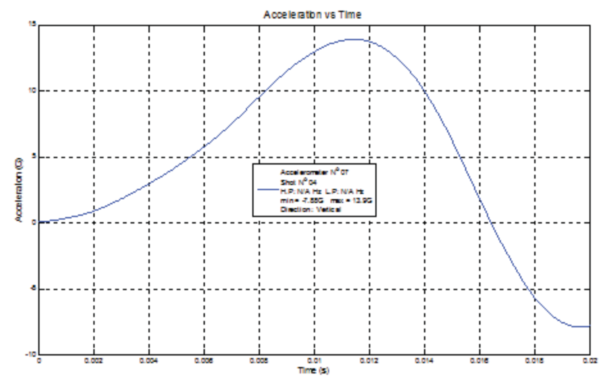
Figure 9 - Acceleration/Time Plot for 3.5” Anvil Travel

34. Figures 10 and 11 show the initial pulse from maximum hammer height blows and a review of these shows that the impact g-levels are now within the desired range below 20-g. Hammer release heights are increased so that they are more controllable and repeatable. Pulse durations have also increased by approximately 300 % to 16 ms which is an improvement, but is still shorter than desired.



Shot 03 (first pulse): Hybrid Solution – H.H.: 12”
A.T.: 1.5”; Min: -6.1G; Max: 14.4G; Δt = 16 ms

Figure 10 - Shock Impulse at 1.5” Anvil Travel



Shot 04 (first pulse): Hybrid Solution – H.H.: 10”
A.T.: 3.5”; Min: -7.9G; Max: 13.9G; Δt = 16 ms

Figure 11 - Shock Impulse at 3.5” Anvil Travel

35. The next task in exploratory testing was to investigate methods of eliminating or mitigating the high energy impacts as the anvil contacted the upper and lower stops and it was expected that elastomeric pad or air bladder arrangement could be developed. This effort had just started when a meeting was held at NETE that brought together the members of an international collaboration group involved in the testing and evaluation of HSC shock mitigating seats. Members of the group included Canadian representatives from DRDC(A), CANSOFCOM and NETE; United Kingdom representatives from the Defence Science and Technology Laboratory; and representatives from the United States Special Operations Command’s Special Operations Research, Development and Acquisition Center; the Naval Surface Warfare Center Carderock Division; The Columbia Group; and Duke University’s Department of Biomedical Engineering.

36. NETE presented details of the work done to that date and invited all attendees to inspect all of the available shock mitigating seats and witness a representative blow on the MWSTM. The machine was set-up with a nitrile impact attenuator fitted to the hammer, the steel dummy test load installed, anvil travel set to 3.5” and the hammer release height set to 10”. After viewing the actions of the machine anvil and attached dummy test load in real time and reviewing the low motion video, there was a general consensus from the attendees that the initial pulse shape was acceptable, but that the duration needed to be extended. However, of more concern was the decaying rebound experienced after the initial impact that is an inherent characteristic of the machine. The rebound effect was not ideal because the relatively long rebound period would tend to mask the characteristics of each seat’s shock attenuation system and make the long term aim of developing numerical models very difficult.

37. As a result of the discussions, DRDC(A) with CANSOFCOM’s concurrence, requested that NETE stop testing using the MWSTM with a hard-mounted seat interface and investigate the possibility of developing an interface that would decouple or separate the seat/seat interface from machine anvil, avoid any rebound and extend the duration of the impact reaction.

Decoupled Shock Mitigating Seat Test Fixture

38. Developing the decoupled test fixture required that the following constraints be considered:

a. the MWSTM must not be modified in any permanent way;

b. the new fixture should not require new anchoring points in the existing concrete structures;

c. the new test fixture should be easy to install and remove; and

d. the new fixture should be operable with the available services such as electrical power, compressed air, etc.

39. Essential requirements for the decoupled test rig would include:

a. suitability for use with test specimens up to 450 kg;

b. a minimum of 3.0 metre vertical clearance;

c. a minimum interface vertical travel of 0.3 metres;

d. a shock impulse target of 40 g and 100 msec;

e. a minimum table size of 1.0 metre x 1.5 metre with minimal flexing under shock loading;

f. interface vertical travel to be arrested at the point of zero velocity; and

g. guides to ensure interface experiences minimum lateral movement.

40. Site and equipment surveys were conducted and it was determined that it should be possible to develop a design that would be easy to install and remove without requiring permanent MWSTM modification or invasive changes to the supporting concrete structure. Available shop services should also be sufficient.

41. Meeting the design constraints meant that the table size would have to be increased and the size selected was approximately 2.0 metres long and 1.5 metres wide. To provide the required table stiffness a substantial structural steel grillage structure was developed. This had a lower footprint that was flat and slightly smaller than the machine's anvil top to suit the insertion of shock attenuating materials. Because of the machine's location, there was no vertical clearance restriction. Guide posts were positioned at each corner to control the table's vertical travel and prevent lateral movement. These posts would be securely attached to the test fixture's base and the posts were long enough to ensure that 0.3 metres vertical travel was possible. A removable frame, bolted to the top of the guide posts helped to increase the fixture's rigidity. This frame also provided the structure required for the installation of wire hoists that would be used to raise and

lower the test table. Figures 12 and 13 show the plan views and elevations of completed decoupled shock mitigating test fixture.

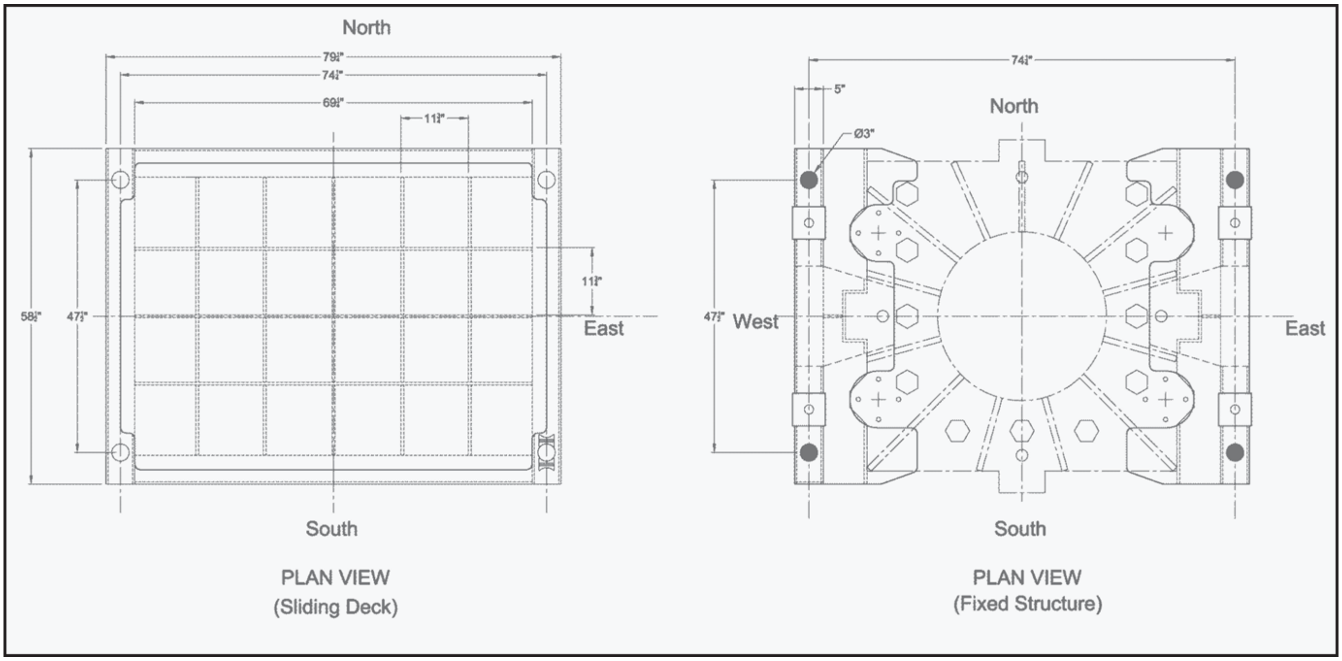


Figure 12 - Decoupled Shock Mitigating Test Fixture Plan Views

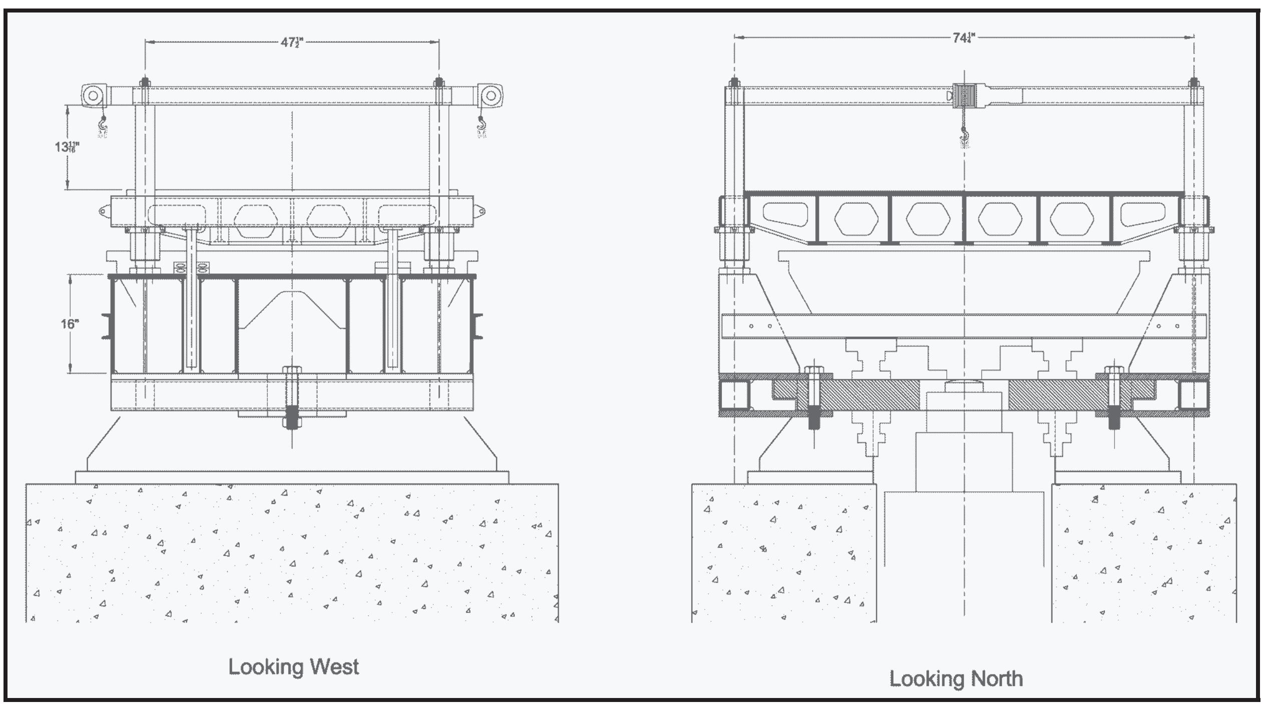


Figure 13 - Decoupled Shock Mitigating Test Fixture Elevations

42. Having the ability to arrest the table's vertical travel at the point of zero velocity provided the greatest design challenge. Considered options were mechanical stops using multi-track, small-

pitch ratchets or spring-loaded clutch plates; pneumatic or hydraulic dampers configured to have free extension and highly damped recovery; or shaft locking using pneumatic, hydraulic or electro-magnetic devices.

43. Preliminary detailed designs were developed for each option, suitable components identified, and estimates of material costs, fabrication costs and schedule developed. The results were an estimated total cost (materials and labour) of $122,000 and an aggressive estimated time to complete schedule of 24 to 28 weeks.

Drop Test Machines

44. This potential revision to the test equipment provided an opportunity to revisit the availability of suitable single-impact, test machines that more closely match machine characteristics to the slam event vertical acceleration/time profile shown in Figure 1. It had always been recognised that the MWSTM could not simulate the Zone (a) free-fall portion of the slam event that unloads the suspension system. Also the impact direction was the reverse of the slam event direction.

45. A limited market survey was conducted and two COTS systems were identified and these were:

a. Benchmark Electronics, Inc.'s Model AVEX SM-220; and

b. Lansmont Corporation's Model M95/115 Shock Test System.

46. The AVEX SM-220, shown below in Photograph 5, has a compact design and utilises a powered test specimen drop rather than a free-fall drop. It is firmware controlled with a pneumatically powered stroke and brake where the stroke and air pressure determines impact velocity and the brake prevents undesirable rebound. The machine has a maximum stroke of 21" and is capable of achieving the desired half-sine pulse at a cycle rate of up to eight cycles per minute with an impact velocity in the 5 m/sec range. Pulse profile is adjusted by installing pulse generators of differing materials and thicknesses at the point of impact. The manufacturer's standard pulse generators would not provide the desired pulse duration, but it was expected this could be achieved with some experimentation. Test specimen weights of 1000 lb could be accommodated up to a maximum 50 g-level and a 36" x 36" magnesium table can be fitted. The machine would be operable with existing shop services and would not need a poured concrete seismic mass because the base acts as an inertial mass and is supported on air mounts. This unit was available with a 20-week lead time and a cost of $80,000.

Photograph 5 - Benchmark Electronics, Inc.'s Model AVEX SM-220

47. Lansmont Corp.'s M95/110, shown in Photograph 6, is a more conventional free-fall drop test machine with available refinements that make it potentially suitable for the seat testing application. It is firmware controlled with a pneumatically powered brake that is used to prevent rebound. The tower is 15'-8" high with a 37" x 45" aluminum table and a maximum test specimen weight of 2500 lb. An impact velocity of 7.3 m/sec and 25 g is achievable. A half-sine pulse with durations in excess of 100 ms is achievable using the manufacturer's adjustable Opposing Force Gas Programmer (OFGP). This unit also could operate with existing shop services, but would need a concrete seismic mass. This unit was available with a 20-week lead time and a cost of $146,525 that includes $44,000 for the OFGP.

Photograph 6 - Lansmont Corp.'s M95/110

48. The details of the Decoupled Shock Mitigating Seat Test Fixture and the COTS drop test machines were presented to DRDC(A) and CANSOFCOM for their review. The information provided would enable the making the decision on the way ahead given the potential risks inherent in developing a new test fixture and the additional costs for the manufacturer's new test fixture or the less risk acquisition of a proven COTS drop test machine.

49. A compromise solution could be to use a suitable test machine at another facility and one potential candidate was the drop tower test facility located at the Munitions Experimental Test Centre (METC) at DRDC Valcartier (V). Activities conducted at this facility include investigations into methods of mitigating the effects of improvised explosive devices on the structures and occupants of army vehicles. The methods of shock attenuation include seat suspension systems and shock attenuating materials and the knowledge gained from this work could be beneficial to the seat testing program.

50. As a result of discussions and a site visit, it was decided that an initial series of exploratory tests would be conducted at the METC facility to demonstrate both the feasibility of using the drop tower test machine and providing the experimental data required to develop an acceptable test methodology.

<u>Seat Testing Program at DRDC(V)</u>

51. The test program to be conducted at DRDC(V) would use that facility's drop test tower (see Photograph 7). The tower consists of large seismic mass below floor level, a large and heavy steel sub-base, two heavy-walled, segmented, steel pipe posts approximately 4 metres long, a guided seat attachment platform and carriage and a winch system to raise and lower the carriage. The seat attachment platform (grey) is bolted to the carriage (light blue) and both are shown in Photograph 8 as is the ballast weight discussed below. Low friction guide rollers and adjustable alignment guides allow the carriage to fall with minimal friction losses. The photograph also shows the heavy duty steel impactor stool that was fabricated and installed for the initial characterisation tests. The impact surface on the underside of the test specimen platform was also enlarged for the testing.

Photograph 7 - DRDC(V) Drop Test Tower Installation

Photograph 8 - Drop Test Tower Carriage (Blue), Seat Attachment Platform and Ballast Weight (Grey)

52. For the test program, a constant load procedure would be used because of the varying payloads (seat weights and number of manikins). For the exploratory tests, a 215 kg fabricated ballast weight was bolted to the seat attachment platform and the total falling mass was 655 kg (see Photograph 9). Initially, a constant drop height of approximately 2.47 m was used.

Photograph 9 - Accelerometers Under Evaluation on Ballast

53. Exploratory testing also provided an opportunity to evaluate the responses of different types of accelerometer and enable the selection of the most suitable technology and device for the test program. The three accelerometers were mounted on the top plate of the ballast (see Photograph 9) and these were:

a. Endevco Corp. Model 2262A, 200-g, single-axis, piezoresistive accelerometer (on the left);

b. Silicon Design Inc., Model 2460-050, 50-g, tri-axial, Micro-electro-mechanical system (MEMS) accelerometer module (in the middle); and

c. PCB Piezotronics, Model 352C34,50-g, single-axis, Integrated Circuit Piezoelectric accelerometer (to the right).

54. Acceleration data were collected at a sampling rate of 20 kHz using a Dewetron Inc. DEWE-571 rugged, data acquisition system. A data acquisition pre-trigger was used to ensure that the acceleration data for complete drop sequence was captured and the data were post-processed using a 250 Hz low pass filter.

55. A comprehensive array of video and photographic equipment was used to provide a visual record of the individual tests. A digital camera recorded details of the set-up before and after each test. Standard video equipment recorded events in real time and high-speed video equipment captured of close-up views of each impact. A separate stereo, high-speed video camera set-up was

also used to provide a capability of post-processing event displacements and velocities in three dimensions. An overview of the camera set-up is shown in Photograph 10. Specialised software was also available to enable the tracking of specific points-of-interest on the test equipment during the events. Tracking specific points made it possible to determine velocity accurately, as well as the movement of specific points relative to other points.

Photograph 10 - Views of the Video and Lighting Equipment Set-Up

56. The high speed video equipment used during the characterisation testing was as follows:

a. Photron USA Inc. FASTCAM APX-RS Camera (2 off);

b. Photron USA Inc. FASTCAM SA1.1 Camera (2 off); and

c. Photron USA Inc. FASTCAM MC2 Dual Head Camera.

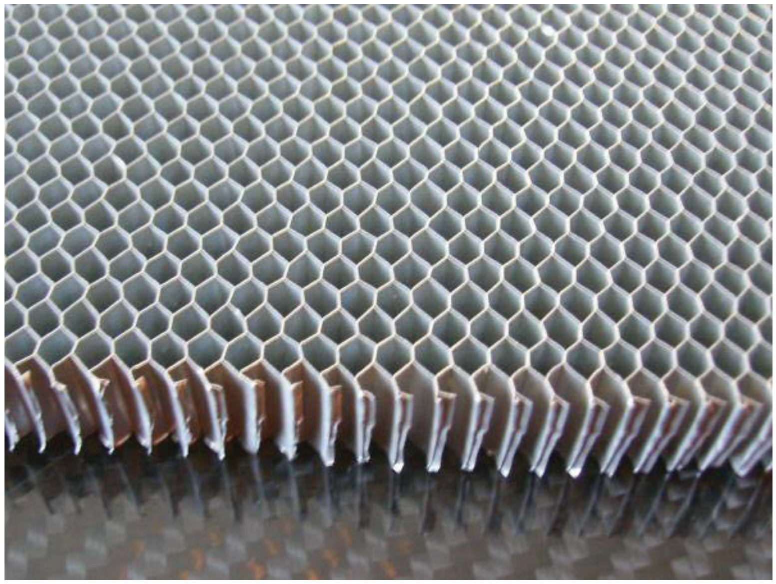
57. Xcitex, Inc. ProAnalyst motion analysis software was used to post-process the high-speed video files and the software's 3-D Analysis module was used to provide displacement tracking data.

58. Additional equipment included two GoPro HERO3 video cameras that recorded the events in real time and an array of high intensity lights.

59. DRDC(V) staff proposed the use of lightweight, aluminum, honeycomb material as the shock attenuating material. This material has a relatively long history in energy absorption applications and, as an example, was used as a decelerator in the landing gear struts of the Apollo 11 moon mission's lunar module in 1969. It is currently used in the aerospace, automotive and transportation industries because of its predictable and repeatable energy absorption properties, high crush-to-weight ratio, constant force crush curve, wide range of strengths (controlled by foil thickness and cell size), long crush stroke (in excess of 75%), use at elevated temperatures and resistance to moisture and corrosion. Photograph 11 shows views of a sample of a 1/8" cell size, aluminum, honeycomb material that is the result of a high-tolerance manufacturing process that has strips of flat aluminum foil joined together using staggered lines of glue. Once the glue has set, the layered sheet is pulled transversely and expanded to form the distinctive honeycomb pattern.

Photograph 11(a) - Top View of Honeycomb Impactor Element

Photograph 11(b) - Side View of the Honeycomb Impactor Element



Photograph 11 (c) - Close-Up of 1/8” Honeycomb Cells

Photograph 11 - Honeycomb Panel

60. For the exploratory tests, a selection of non-perforated, honeycomb panels manufactured from 5052 aluminum alloy were acquired in three specifications[3] as detailed in Table 2. In the table, the shear strength and modulus are further divided into columns “L” which is shearing in the direction of the aluminum ribbons and “W” which is shearing in the direction perpendicular to the ribbons. Panel material specifications follow a standard format where the density of the expanded panel listed in lb/ft^3 followed by the honeycomb cell size in inches and the aluminum foil thickness in inches. Panels are available in many standard thicknesses and for these tests, 2” and 4” thick panels were bought.

Table 2 - Material Characteristics (SI units)

Material Specification (Lb/ft^3-inch–inch)	Stabilized Compressive Strength (MPa)	Crush Strength (MPa)	Shear Strength (MPa)		Shear Modulus (MPa)	
			L	W	L	W
4.5 – 1/8 – 0.0010	4.00	1.86	2.38	1.55	352	172
8.1 – 1/8 – 0.0020	10.86	5.24	5.58	3.72	772	345
1.6 – 3/8 – 0.0010	0.68	0.34	0.61	0.35	90	41

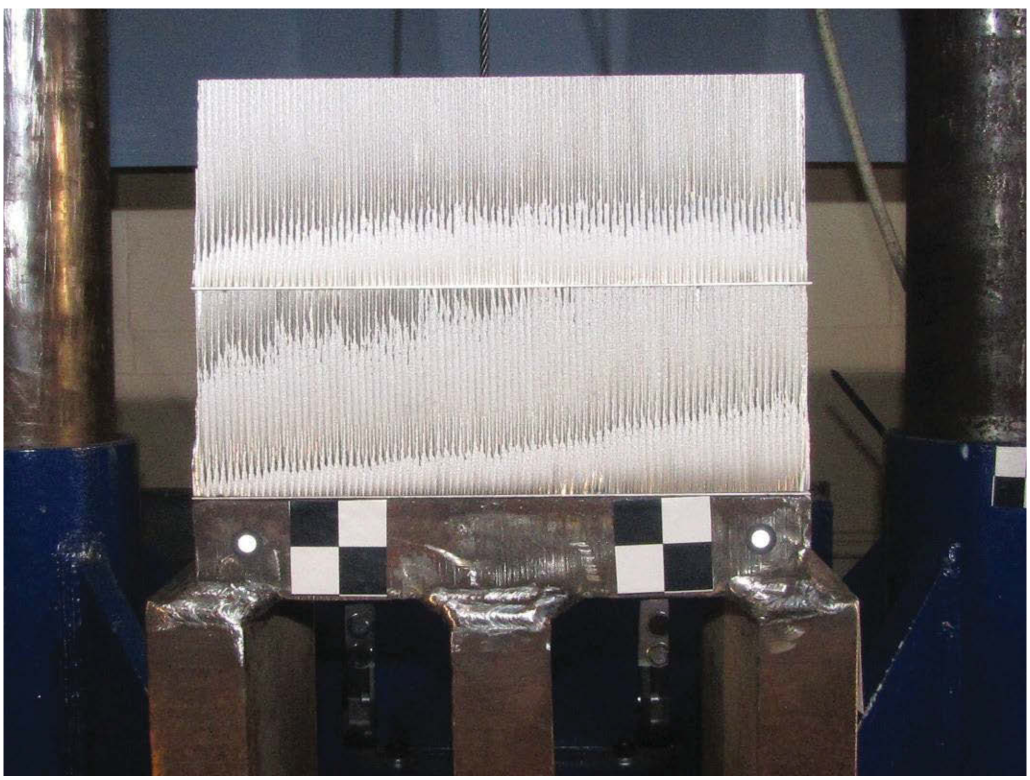
61. In all, ten characterisation tests were conducted using samples of all available materials with varying impact areas and differing impactor drop heights. Impactor crush area and height were determined using a method similar to that described in Reference D. Drop height and, therefore, impact velocity, remained nominally constant. Table 3 details the complete test matrix.

[3] Alcore PAA-CORE™ 5052 Aluminum Honeycomb Product Data Sheet, June 2003

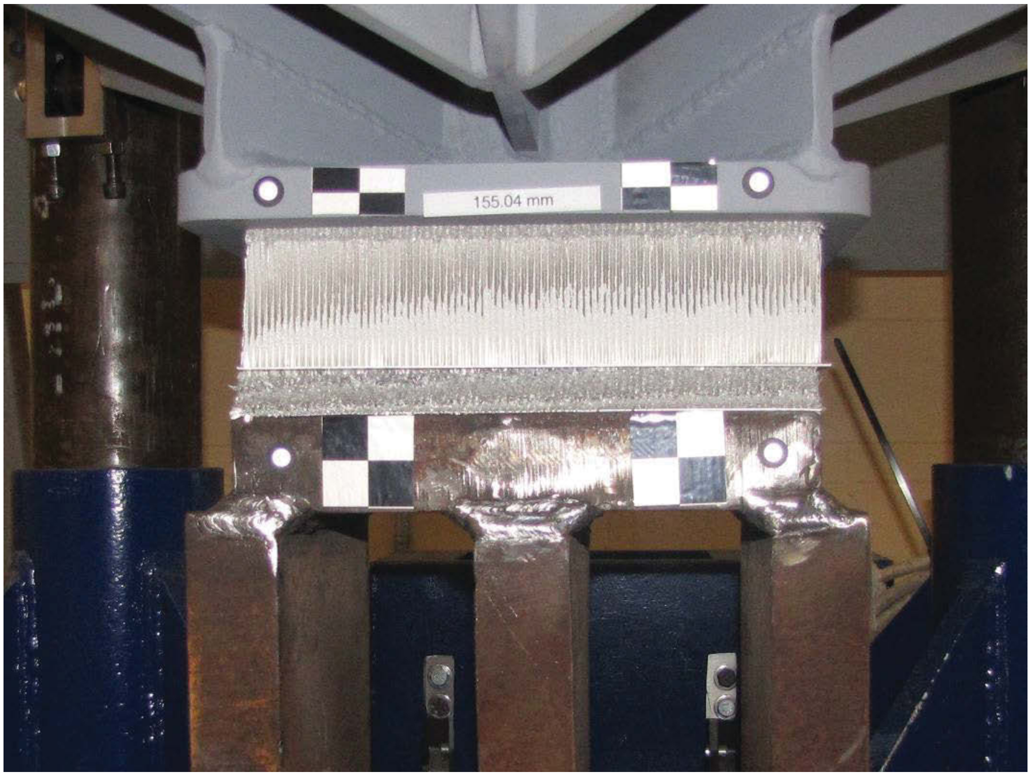
Table 3 - Characterisation Test Matrix

Test ID	Material Density (Lb/ft^3)	Crush Area (m^2)	Crush Strength (MPa)	Impactor Height (m)
T01	4.5	0.031	1.8	0.2
T02	8.1	0.076	5.85	0.15
T03	8.1	0.076	5.8	0.1
T04	4.5	0.09	1.8	0.2
T05	4.5	0.09	1.8	0.2
T06	4.5	0.09	1.8	0.2
T07	1.6 & 4.5	0.062	0.34	0.5
T08	4.5	0.09	1.8	0.171
T09	4.5	0.03 & 0.09	1.8	0.2
T10	1.6	0.06 & 0.09	0.34	0.6

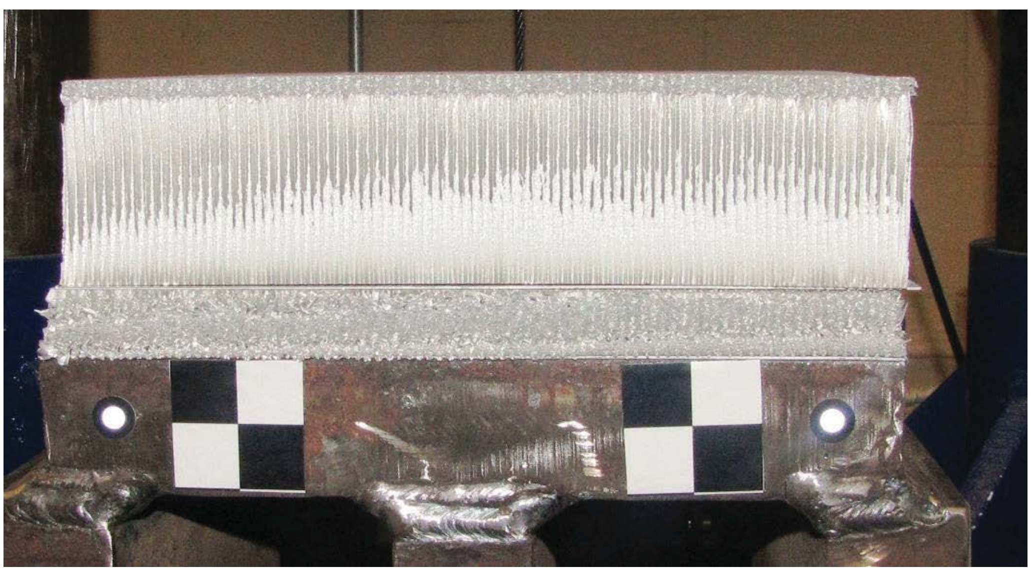
62. Photographs 12, 13 and 14 show the impactor used in Test T06 prior to and after the impact. Note that the impactor elements are separated by a square piece of aluminum sheet and a similar sized piece is placed between the lower impactor element and the steel impactor stool.



Photograph 12 - Impactor Before Impact



Photograph 13 - Impactor After Impact



Photograph 14 - Close-Up of Impactor Showing Crushing Variation of Both Elements

63. The following figures were prepared by DRDC(V) and show the results of the characterisation tests. Figure 14 shows the range of g-levels attained. Figure 15 shows the repeatability of the shock attenuation and Figure 16 shows the correlation between the accelerometer data and the visual tracking data.

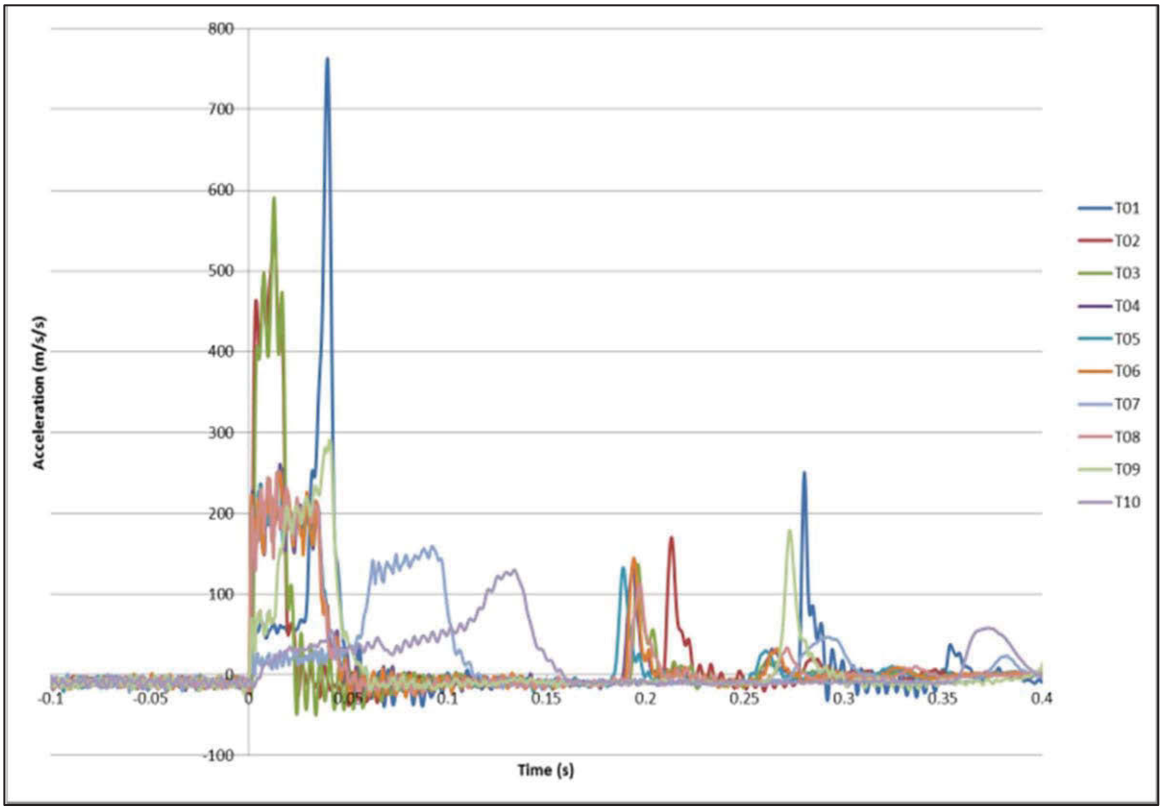


Figure 14 - Acceleration Levels Attained During Characterisation Test

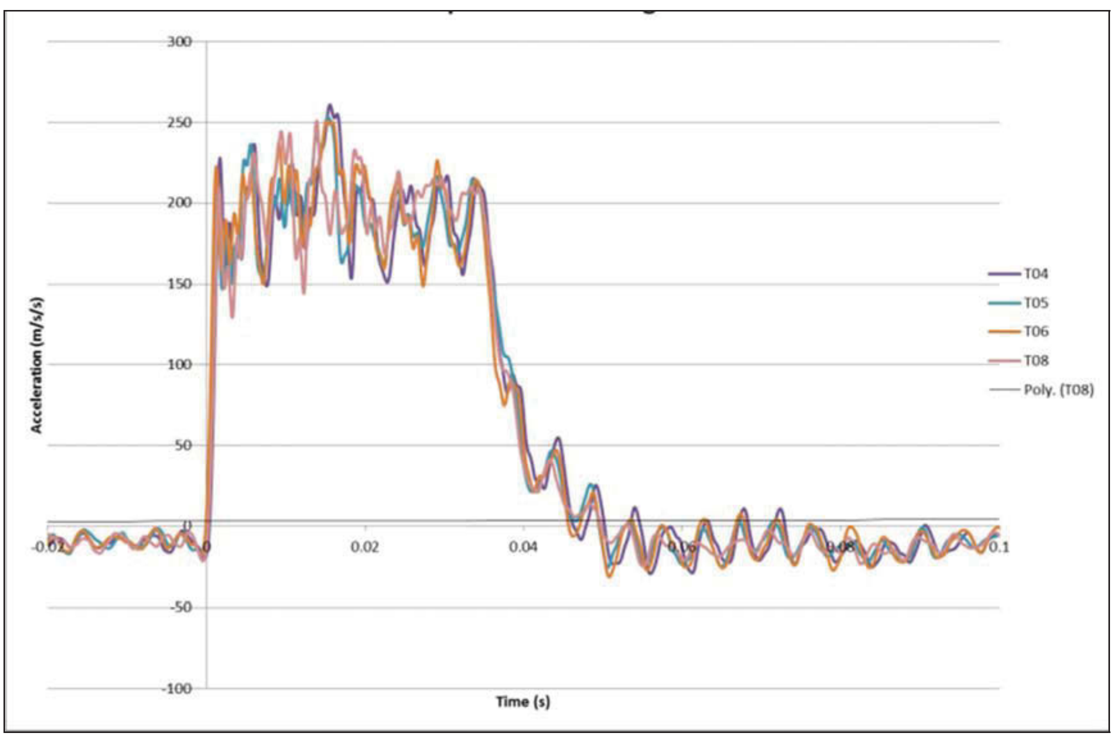


Figure 15 - Repeatability Attained During Characterisation Tests

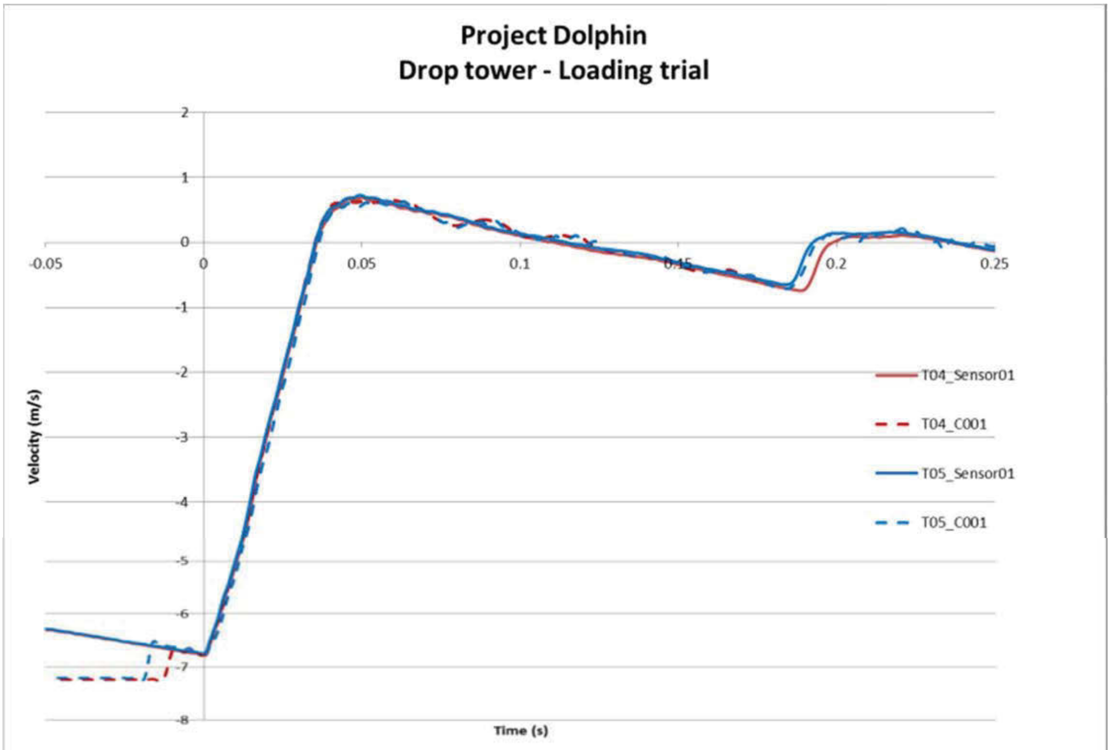


Figure 16 - Accelerometer Data and the Visual Tracking Data Correlation

64. Analysis of the results demonstrated that:

a. the method used to calculate the aluminum honeycomb density, area and impact height was successful in predicting the measured g-levels;

b. acceleration levels between 3 and 75 g at durations between 30 and 150 ms were achievable under this test set-up;

c. tests demonstrated good repeatability;

d. the piezo-resistive and Micro Electro Mechanical Sensor (MEMS) accelerometers performed similarly and the former would be used for the test program because of stock availability;

e. good correlation between imaging analysis and metrology was possible; and

f. some rebound was observed possibly due to compression and subsequent expansion and release of air trapped within the honeycomb cells during the crush phase of the impact.

65. With the successful completion of the characterisation testing, DRDC(A), DRDC(V) and NETE proceeded to collaborate and develop the test program. The majority of the tests would be conducted with an instrumented crash test dummy, the Hybrid III anthropomorphic test device (ATD), placed on the seats with a posture that would ensure a realistic spine alignment and provide

a comprehensive and realistic representation of the human body's reaction to applied forces, as well as the seat response to the full impact cycle where the seat is unloaded during free-fall and loaded as the seat decelerates and the ATD continues to accelerate into the seat cushion.

66. The ATD used for the testing represents a 50th percentile male with a mass of 77.7 kg (171 lb) and is used extensively by DRDC(V) for similar experiments. The ATD was fitted with four accelerometers and six load cells. An impactor force measurement device was fabricated that included four load cells and this was installed on top of the impactor stool. Each seat structure was fitted with three accelerometers. The instrumentation was completed with a seat pad accelerometer that was installed on top of the seat cushion and a reference accelerometer was fitted on the platform base. Table 4 details NETE's data acquisition system's sensors including their measurement axis and Table 5 details the METC data acquisition system's sensors. Photograph 15 shows the typical sensor placement.

Table 4 - NETE Sensors Locations with the ATD on a Seat

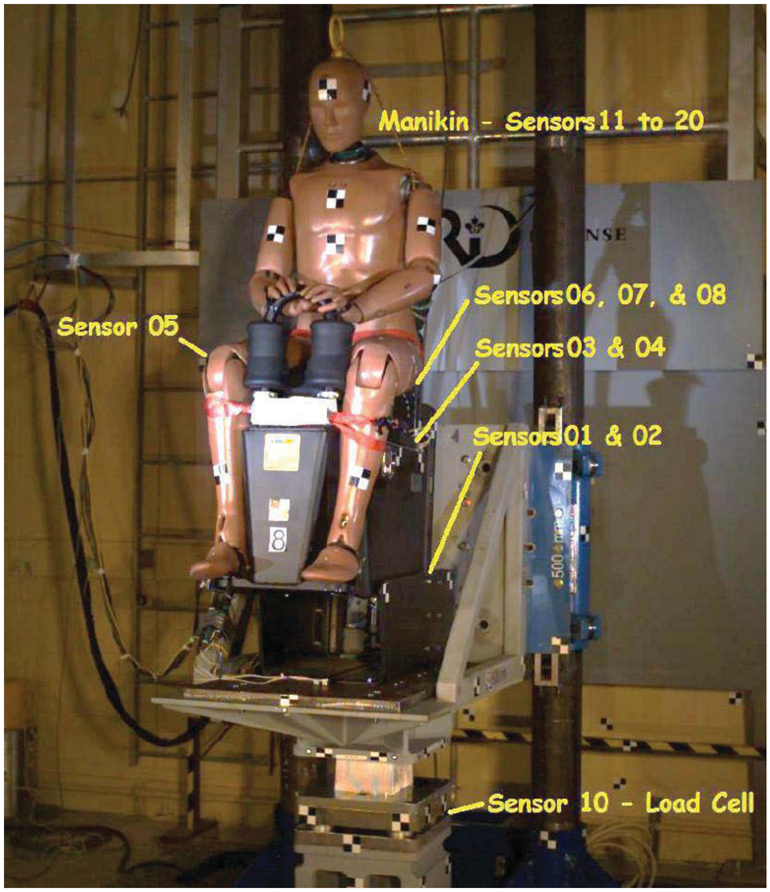
Description	Axis*	Number	Type	Model	Technical Support
Platform Acceleration	A_Z	Sensor 01	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 02	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Pan Acceleration	A_Z	Sensor 03	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 04	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Pan Acceleration	A_Z	Sensor 05	Piezo-Resistive Accelerometer	Endevco 7264D	NETE
Seat pad Acceleration	A_Z	Sensor 06	IEPE Accelerometer	B&K 4515-B-002	NETE
	A_X	Sensor 07	IEPE Accelerometer	B&K 4515-B-002	NETE
	A_Y	Sensor 08	IEPE Accelerometer	B&K 4515-B-002	NETE

* Axis Direction: *Z* = Vertical; *X* = Front to Back; *Y* = Side to Side.

Table 5 - METC Sensors Locations with the ATD on a Seat

Description	Axis*	Number	Type	Model	Technical Support
Impactor Force	F_Z	Sensor 10	Load Cell (Total)	PCB 207C	METC
	F_{Z1}	Sensor 21	Load Cell N^{o}1 – Front Left	PCB 207C	METC
	F_{Z2}	Sensor 22	Load Cell N^{o}2 – Back Left	PCB 207C	METC
	F_{Z3}	Sensor 23	Load Cell N^{o}3 – Front Right	PCB 207C	METC
	F_{Z4}	Sensor 24	Load Cell N^{o}4 – Back Right	PCB 207C	METC
ATD Pelvis Acceleration	A_Z	Sensor 11	Accelerometer	Endevco 7264D	METC
	A_X	Sensor 12	Accelerometer	Endevco 7264D	METC
ATD Chest Acceleration	A_Z	Sensor 13	Accelerometer	Endevco 7264D	METC
	A_X	Sensor 14	Accelerometer	Endevco 7264D	METC
ATD Lumbar Force	F_Z	Sensor 15	Load Cell	Denton 4609	METC
	F_X	Sensor 16	Load Cell	Denton 4609	METC
	M_Y	Sensor 17	Load Cell	Denton 4609	METC
ATD Neck Force & Moment	F_Z	Sensor 18	Load Cell	Denton 1716	METC
	F_X	Sensor 19	Load Cell	Denton 1716	METC
	M_Y	Sensor 20	Load Cell	Denton 1716	METC

* Axis Direction: *Z* = Vertical; *X* = Front to Back; *Y* = Side to Side.



Photograph 15 - Typical Sensor Layout

67. The dynamic interaction that occurs between the seat and ATD during a complete drop test loading cycle increases the difficulty for DRDC(A) developing numerical models that simulate the function of the shock mitigating seats. Therefore, two additional series for drop tests were conducted and for these the ATD and seat cushions were removed. Steel rigid masses were installed on the upper surface of the seats. The first mass was 84 kg (185 lb) that represented the combined mass of the ATD and seat cushion. The second mass was 116 kg (255 lb) that was representative of heavier 95th percentile male occupants that is more representative of a fully outfitted assaulter. This set-up would mean that the seat suspension systems could be simplified for analysis and modeling and be represented as a single degree of freedom system.

68. Although 13 seats were available, it was necessary to limit the test program to the four single jockey style seats from Shockwave, SHOXS, Ullman and Zodiac because of budget and time constraints. The program, conducted in four phases, would demonstrate the performance of the seats at three impact velocities and two shock loading (acceleration) rates with the ATD in place and with two rigid masses. The impact velocity targets were 2.5, 4.5 and 6.5 m/s for all phases and the target shock loading level was nine-g for Phases 1, 2 and 3, and four-g for Phase 4. For Phases 1 and 2, the seats tested were from the initial seat acquisition batch and included the Shockwave, SHOXS and Ullman Jockey Pod seats. Phases 3 and 4 tested the new jockey pod seats, acquired from Shockwave and SHOXS, were tested along with the Zodiac jockey pod seat that replaced the Ullman seat.

69. The conditions tested during each test phase were as follows:

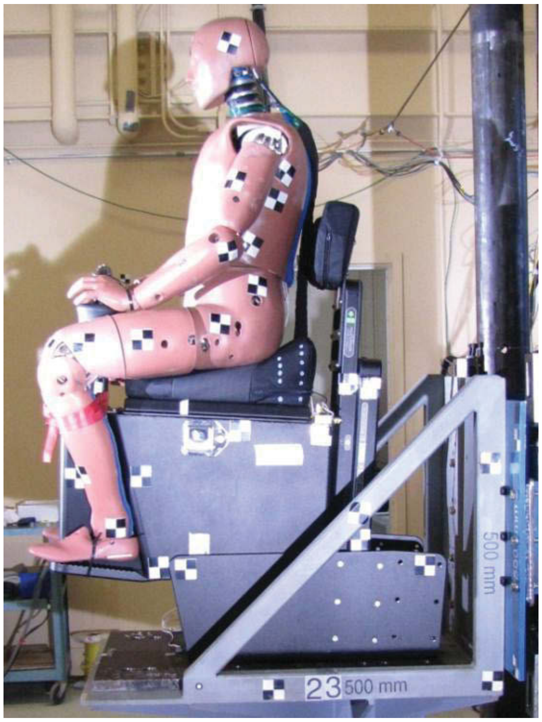
a. Phase 1, conducted during April 2013, was used to confirm the validity of the test set-up and perform initial tests on the first candidate seat to ensure that both data acquisition systems, the video systems and the triggering system functioned correctly and that the data collected provided the required information. Initial drops used a 215 kg rigid ballast mass attached to the drop test machine's carriage and validated the method of determining area, depth and placement of the aluminum honeycomb impactor. For this initial phase of the seat testing, three loading conditions would be tested at three targeted impact velocities and in all, 24 tests were conducted. The impactor was designed to achieve an acceleration rate in the nine-g range and used between one and four layers of 101.6 mm thick, 4.5 lb/ft^3 aluminum honeycomb. The loading conditions were with the rigid ballast mass, the Shockwave Jockey Pod seat with the ATD and the same seat with the cushion removed and an 81.8 kg rigid mass fitted. The targeted impact velocities were 2.5, 4.5 and 6.5 m/s. Details of the complete Test Sequence can be found in Annex A;

b. Phase 2, conducted during May 2013, consisted of testing the Shockwave, SHOXS and Ullman jockey seats (see Photographs 16 and 17). In all, 37 tests were conducted using one, two or three layers of 101.6 mm thick, 4.5 lb/ft^3 aluminum honeycomb as the attenuators and details of the test sequence can be found in Annex B and briefly described below:

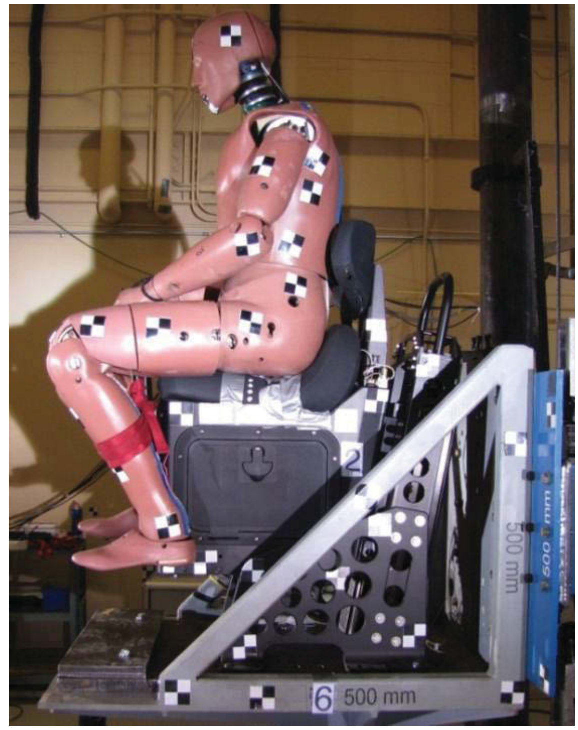
(1) the Shockwave seat tests continued on from Phase 1 and repeated the series of tests with the Shockwave Jockey Pod seat with the ATD. This was done to demonstrate that no significant change in test conditions had occurred during the pause in the test program. The Shockwave tests were limited to three single drops at each impact velocity with the ATD for validation purposes and three single drops at each impact velocity with the 116 kg rigid mass fitted. Multiple drops at each impact velocity were not conducted because of the severity of this test condition and the possibility of damaging the seat;

(2) the SHOXS Jockey Pod seat was tested using a similar series of loading conditions as the Shockwave seat, namely three targeted impact velocities of 2.5, 4.5 and 6.5 m/s with the ATD fitted, with the cushion removed and a rigid 81.8 kg rigid mass fitted. Tests with the 116 kg rigid mass fitted were limited to the 2.5 and 4.5 m/s impact velocities because the seats attenuator neared its travel limit and conducting the final test condition would likely have resulted in significant damage to the seat assembly; and

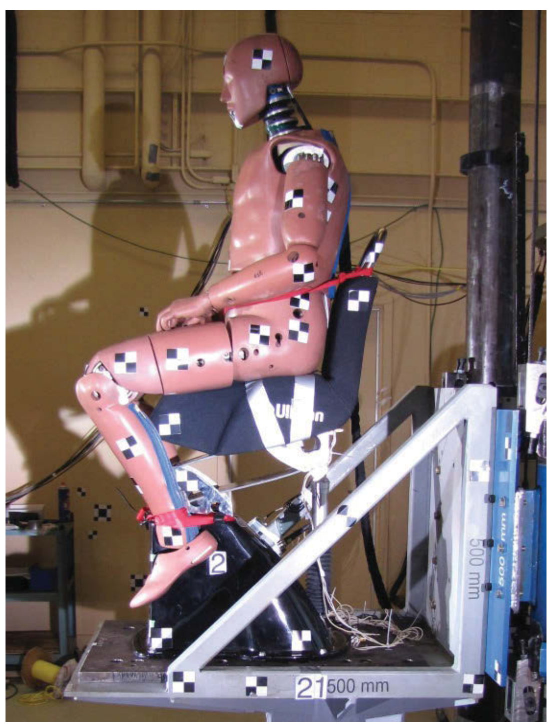
(3) the Ullman seat was also tested using a similar series of loading conditions with the exceptions that the 6.5 m/s impact velocities for both the 81.8 kg and 116 kg rigid mass tests were not conducted because of the high potential for significant damage to the seat assembly.



(a) Shockwave Jockey Pod Seat

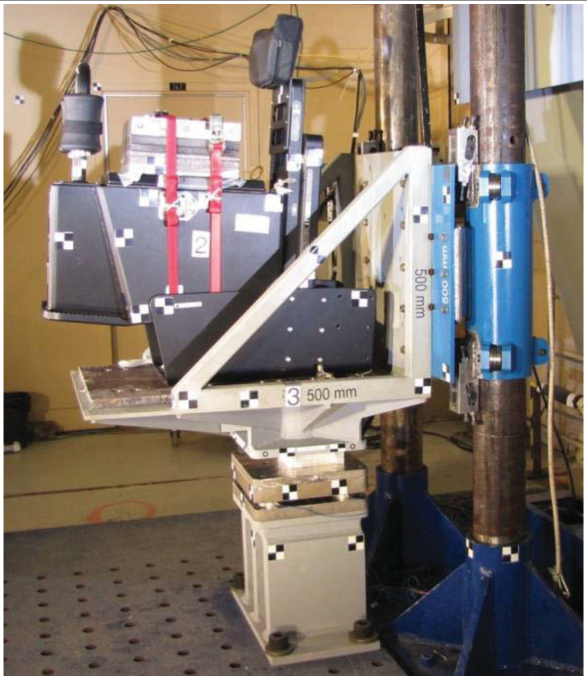


(b) SHOXS Jockey Pod Seat

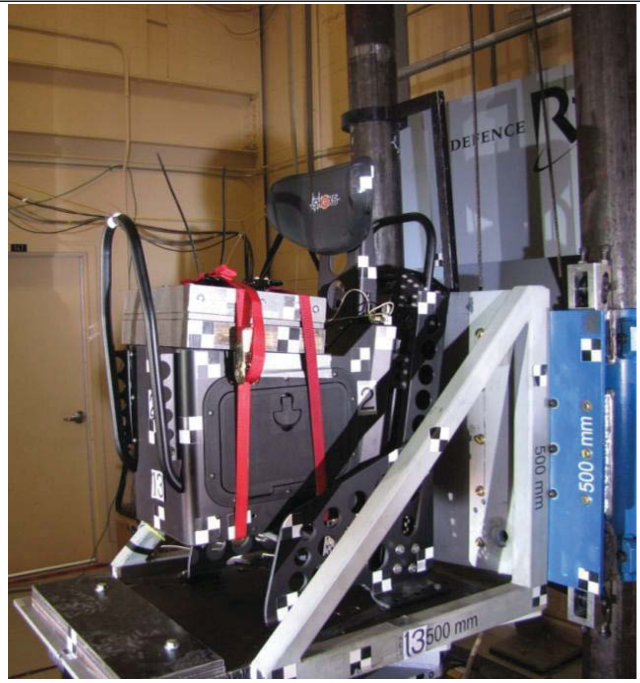


(c) Ullman Jockey Seat

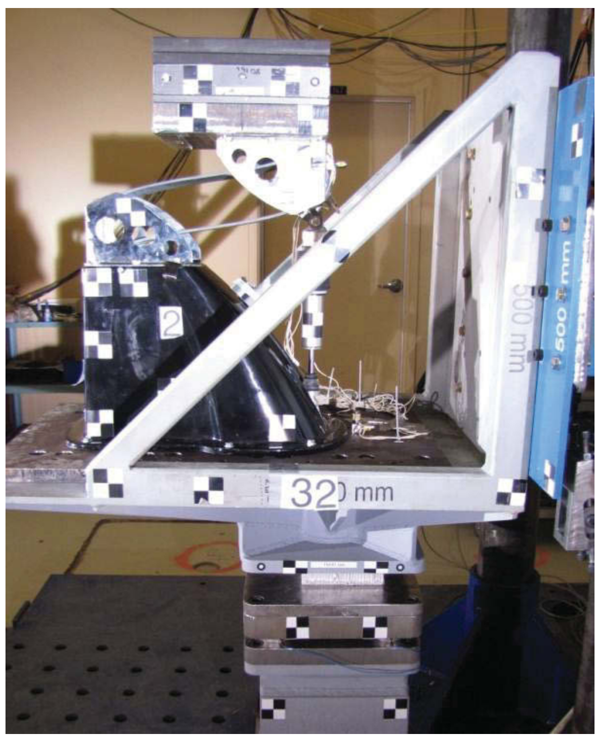
Photograph 16 - Phase 2 Test Set-Up with the ATD Installed



(a) Shockwave Jockey Pod Seat
with Rigid Ballast Installed



(b) SHOXS Pod Seat
with Rigid Ballast Installed



(c) Ullman Jockey Seat with Rigid Ballast Installed

Photograph 17 - Phase 2 Test Set-Up with the Rigid Mass Installed

c. Phase 3, conducted during December 2013, consisted of testing the Shockwave, SHOXS and Zodiac Jockey Pod seats (see Photograph 18). In all, 21 tests were conducted using the 50th percentile ATD and one, two or three layers of 101.6 mm thick, 4.5 lb/ft^3 aluminum honeycomb attenuator to achieve a target shock loading in the nine-g range. The primary purpose of this series of tests was to document if any significant difference in performance could be detected between the old and new versions of the Shockwave and SHOXS seats. The performance of the Zodiac seat would also be documented. No rigid mass tests were conducted and details of the test sequence can be found in Annex C and briefly described below:

(1) the Shockwave seat test was conducted with the ATD. The Shockwave tests consisted of two or three drops at each impact velocity. One additional test was conducted with the seat's shock attenuating gas pressure lowered to 67 psi from the manufacturer's recommended pressure of approximately 100 psi to gauge the effects of this change;

(2) the Zodiac Jockey Pod seat was tested using a similar series of loading conditions as the Shockwave seat, namely three targeted impact velocities of 2.5, 4.5 and 6.5 m/s with the ATD fitted. Two drops were done at each velocity. One additional drop was conducted with the seat's attenuator gas pressure increased from the manufacturer's recommended nominal 70 psi to a nominal 100 psi to document the effects of this change; and

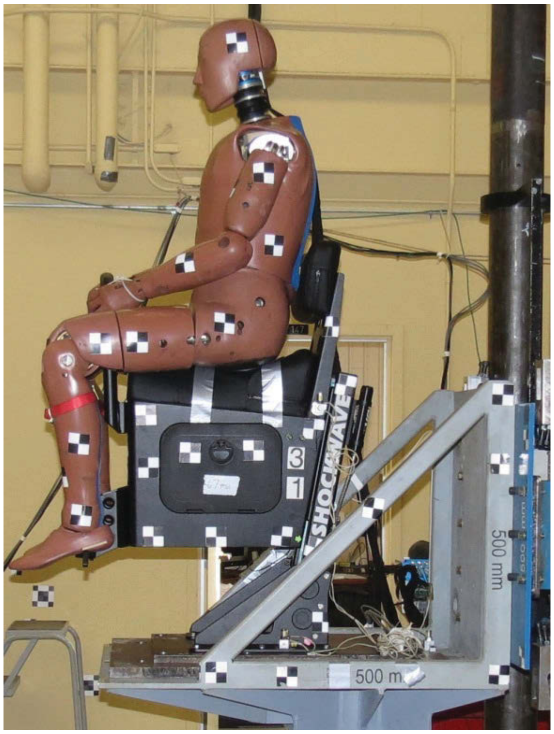
(3) the SHOXS Jockey Pod seat was tested using a similar series of loading conditions as the Shockwave seat, namely three targeted impact velocities of 2.5, 4.5 and 6.5 m/s with the ATD fitted. Two drops were done at each velocity.

d. Phase 4, conducted during January 2014, consisted of testing the Shockwave, SHOXS and Zodiac Jockey Pod seats with a reduced shock loading level. A total of 23 tests were conducted using the 50th percentile ATD and attenuators of two or four layers of 101.6 mm thick, 1.6 lb/ft^3 aluminum honeycomb to achieve a target shock loading in the four-g range. The use of the low-density aluminum honeycomb meant that the impact area and height of the attenuator column would have to be increased to achieve the reduced shock loading requirement. The height required to attenuate the highest velocity impact would need to be increased to a height that would create an unstable column and therefore this test condition was removed from the program. Also, no rigid mass tests were conducted. Details of the test sequence can be found in Annex D and briefly described below:

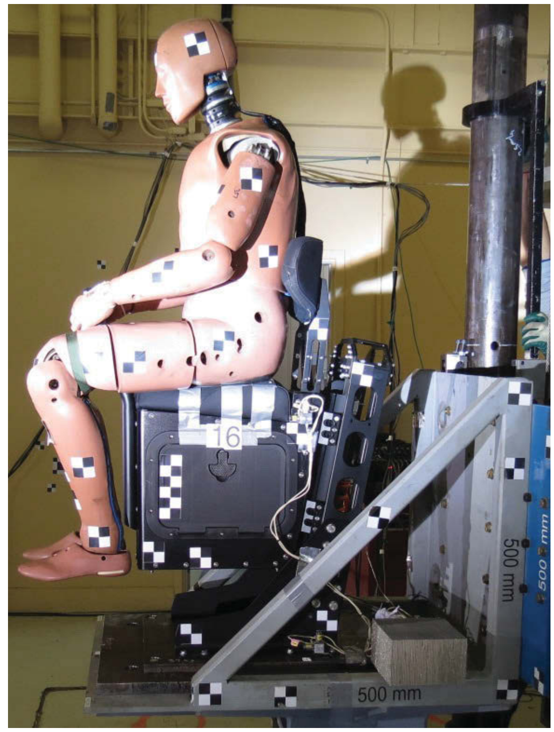
(1) the SHOXS seat test was conducted with the ATD and consisted of three or four drops at the two impact velocities;

(2) the Zodiac Jockey Pod seat was tested at two impact velocities and five drops at the 2.5 m/s impact velocity and four drops at the 4.5 m/s impact velocity. Tests were repeated at both velocities because the attenuator crush was asymmetrical and one or more layers were ejected; and

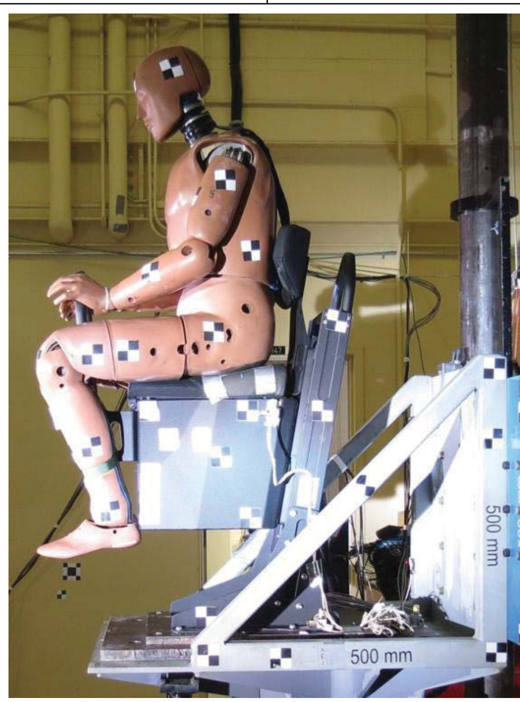
(3) the SHOXS Jockey Pod seat test was conducted with the ATD and consisted of three or four drops at the two impact velocities.



(a) Shockwave Seat



(b) SHOXS Seat



(c) Zodiac Seat

Photograph 18 - Phase 3 Test Set-Up with the ATD Installed

70. The completion of Phase 4 ended the initial seat testing portion of the original R&D initiative and all data and video files were delivered to both DRDC(A) and DRDC(V).

71. DRDC(A)'s initial analysis resulted in the issue of Reference E for Phases 1 and 2 and Reference F for Phases 3 and 4.

72. Finally, it should be noted that the DRDC(V) drop test tower was dismantled at the completion of Phase 4 testing and the construction of an upgraded facility got underway. Construction and commissioning of the new facility is scheduled for completion by late summer 2014.

CONCLUSIONS

73. A collaborative effort involving staff from DRDC(A), DRDC(V) and NETE has been successful in evolving and developing a test protocol for conducting single-impact tests on shock mitigating seats that may be used on board CAF small, high-speed craft.

74. The final test protocol was used for an extensive series of single impact tests on six models of shock mitigating seats from four manufacturers and all visual and numerical data was forwarded to DRDC(A) for analysis and numerical model development.

75. At the initiation of the task, the possibility of using NETE's MWSTM to produce an impact with the desired peak acceleration/time profile was investigated and thought to be possible as experimentation got underway. When the preliminary experimentation results were reviewed by a group of subject matter experts, it was concluded that the initial pulse shape was acceptable, but duration needed to be extended. Of more concern was the relatively long decaying rebound that is an inherent characteristic of the machine. This was thought likely to mask the shock attenuating properties of the seat suspension systems that were the primary focus of the test program and the use of the MWSTM in its standard configuration was suspended.

76. The possibility of decoupling or separating the seat/interface from the medium shock test machine anvil was then investigated as a means of avoiding the rebound effect along with extending the duration of the impact pulse. One major constraint would be that any modifications or additions would not permanently alter the machine or its functionality. A preliminary design for a decoupled device was developed along with estimates of cost and build schedule. Concurrently, a market survey was conducted that identified two COTS single impact drop test machines that could also meet the required energy levels, pulse durations and minimal rebound. Quotations providing cost and estimated lead-times were received. The third option of using a suitable test machine from another facility was also investigated and drop test tower at the DRDC(V) Munitions Experimental Test Centre was identified as being suitable with the bonus that the facility was already involved in somewhat similar, though much higher energy, investigative work on shock attenuation materials and shock attenuation for land vehicle seats. Therefore, for the follow-on work, it was concluded that the use of the DRDC(V) facility had the least risk for schedule delays and was most cost effective.

77. Lightweight aluminum honeycomb material was proposed for use as the shock attenuating material and a series of characterisation tests was conducted to demonstrate that the selected

material, crush area and crush height of the shock attenuator could be calculated. The characterisation tests also enabled the testing of several accelerometers and provided an opportunity to check the appropriateness of the selection of the video equipment, video analysis software, high-intensity lights and video equipment layout. From the analysis of the results of the characterisation tests, it was concluded that;

a. the method used to calculate the aluminum honeycomb density, area and impact height was successful in predicting the measured g-levels;

b. acceleration levels between 3 and 75 g at durations between 30 and 150 ms were achievable under this test set-up;

c. tests demonstrated good repeatability;

d. the piezo-resistive and MEMS accelerometers performed similarly and the former would be used for the test program because of stock availability;

e. good correlation between imaging analysis and metrology was possible; and

f. some rebound was observed possibly due to compression and subsequent expansion and release of air trapped within the honeycomb cells during the crush phase of the impact.

78. Seat testing began and a short series of rigid ballast tests were conducted and from these it was concluded that it was possible to select the attenuator material and properties, impact area, attenuator height and impactor position for the three target impact velocities of 2.5, 4.5 and 6.5 m/s required for the test program.

79. Because of budget and time constraints, only jockey style seats were tested and the test program was split into four phases with a total of 98 tests being conducted. Phases 1 and 2 involved the testing of the Shockwave S1, SHOXS Model 5500 and Ullman Compact seats from the original acquisition program and Phases 3 and 4 involved the testing the newest versions of the Shockwave S1and SHOXS 5500 seats with the addition of a seat from Zodiac Hurricane Technologies Inc.

80. A total of 75 tests were conducted with an instrumented 50th percentile Hybrid III anthropomorphic test device (crash test dummy) installed on the seats. These tests included the use of the three original jockey seats, the three new jockey seats, the three impact velocities and four-g and nine-g target shock loading levels and it was concluded that the ATD and its data acquisition system, provided by the METC and operated by that facilities, staff were successful in collecting pelvis and chest acceleration data, lumbar and neck force data and impactor force data.

81. An additional 23 tests were conducted during Phases 1 and 2 with the rigid steel masses replacing the ATD and seat cushions. One rigid steel mass represented the 50th percentile male and cushion and the second rigid mass represented the 95th percentile male and cushion. The use of the rigid masses avoided the dynamic interaction that occurs between the seat suspension system and ATD during the impact and recovery portions of the drop tests. Analysing the data with the dynamic interaction included would significantly increase the difficulty in DRDC(A)'s

development of the initial shock mitigating seat attenuation system numerical models. These tests involved the three original jockey seats at three impact velocities and the nine-g target shock loading level and it was concluded that the METC instrumentation and data acquisition system was successful in collecting impactor force data and NETE's accelerometers and data acquisition system were successful in acquiring platform, seat pan and seat pad accelerations.

82. All drop tests were recorded using real time and high-speed video and it was concluded that review of the recorded footage immediately after each test provided the information needed to determine if minor correction to the impactor placement was required. The footage would also be useful in the post-test analysis phase when attempting to identify significant events that may have occurred during a test.

83. A separate stereo, high-speed camera set-up was also used to record all drop tests and from the results of initial analysis trials, it was concluded that post processing of these video files using the 3-D analysis module of the Xcitex, Inc. Pro Analysis software would enable the tracking of specific points of interest during any drop test. Analysis of the tracking results will make it possible to determine the velocity of the point accurately, as well as track the movement of multiple points relative to each other or a stationary reference point.

RECOMMENDATIONS

84. As a result of completing the development of a test protocol for and conducting a series of single-impact tests on shock mitigating seats that may be used on board CAF small, high-speed craft it is recommended that:

a. a series of low-g shock level loading tests be conducted in order to confirm the suitability of the shock mitigating seats across the range of sea conditions experienced by rider on board CAF high speed craft; and

b. market surveys aimed at identifying new seat designs or technologies should be conducted on a regular basis.

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Marine Systems Section

Annexes:

Annex A Testing of Shock Mitigating Seats Phase 1 – Shockwave Jockey Pod Seat
Annex B Testing of Shock Mitigating Seats Phase 2 – Shockwave + SHOXS + Ullman Seats
Annex C Testing of Shock Mitigating Seats Phase 3 – Zodiac + Shockwave + SHOXS Seats
Annex D Testing of Shock Mitigating Seats Phase 4 – SHOXS + Zodiac + Shockwave Seats

TESTING OF SHOCK MITIGATING SEATS
PHASE 1 – SHOCKWAVE JOCKEY POD SEAT

TEST SEQUENCE FOR – PHASE 1 – DROP 01 TO 24 – April 2013

1. For the Phase 1 tests a fixed ballast and the Shockwave Jockey Pod seat were tested.

2. The weights of the various "as tested" components are shown in Table 1.

Table 2 – Component Weights

Item	Weight (kg)		
	Ballast	Shockwave	
Carriage	440		
NETE Base Plate	-	93.5	93.5
Ballast	215	-	81.8 (on Seat)
ATD – 50^{th} Percentile Male	-	78.2	-
Seat – Fixed Portion	-	35.9	35.9
Seat – Suspended Portion	-	14.5	10.9 (no cushion)
Total	655	662.1	662.1

3. Table 2 describes the Phase 1 test sequence performed at DRDC Valcartier during April 2013. Ten configurations were tested during 24 drops from three drop heights.

3.1 BALLAST MASS

The main conditions performed with 215 kg rigid ballast installed on the carriage. These were Conditions A, B & C and these tests were used to confirm impactor area, height and placement for three drop heights.

3.2 SHOCKWAVE JOCKEY POD SEAT

The main conditions performed with the 50^{th} percentile ATD on the Shockwave Seat were Conditions D1, D2, E & I.

3.3 SHOCKWAVE JOCKEY POD SEAT WITH NO CUSHION AND A RIGID BALLAST

The main conditions were performed with the 50^{th} percentile ATD and cushion of the Shockwave seat replaced with an 81.8 kg rigid ballast were Conditions F, G and H.

Table 2 – Test Sequence and Configurations

Test ID	Impactor Material Density (lb/ft^3)	Impactor Area (m^2)	Impactor Thickness (mm)
Condition A	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m Ballast Mass on Carriage**		
Drop T1-01	4.5 pcf	0.0292 m^2	4 x 101.6 mm
Drop T1-02	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Drop T1-03	4.5 pcf	0.0292 m^2	2 layers of pre-crushed block
Drop T1-04	4.5 pcf	0.0292 m^2	2 x 101.6 mm (water jet cut)
Drop T1-05	4.5 pcf	0.0292 m^2	2 x 101.6 mm (Band saw cut)
Condition B	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m Ballast Mass on Carriage**		
Drop T1-06	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition C	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m Ballast Mass on Carriage**		
Drop T1-07	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition D.1	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m Shockwave Seat + ATD**		
Drop T1-08	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T1-09	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T1-10	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition D.2	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m Shockwave Seat + ATD (ATD Repositioned on Seat)**		
Drop T1-11	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T1-12	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T1-13	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition E	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m Shockwave Seat + ATD**		
Drop T1-14	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T1-15	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T1-16	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition F	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m Shockwave Seat – No Cushion and 81.8 kg Ballast Weight**		
Drop T1-17	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T1-18	4.5 pcf	0.0292 m^2	2 x 101.6 mm

Table 2 (Cont.) – Test Sequence and Configurations

Test ID	Impactor Material Density (lb/ft^3)	Impactor Area (m^2)	Impactor Thickness (mm)
Condition G	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m Shockwave Seat – No Cushion and 81.8 kg Ballast Weight**		
Drop T1-19	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T1-20	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition H	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m Shockwave Seat – No Cushion and 81.8 kg Ballast Weight**		
Drop T1-21	4.5 pcf	0.303 m^2 Increased area	3 x 101.6 mm
Drop T1-22	4.5 pcf	0.0303 m^2 Increased area	3 x 101.6 mm
Condition I	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m Shockwave Seat + ATD**		
Drop T1-23	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Drop T1-24	4.5 pcf	0.0292 m^2	3 x 101.6 mm

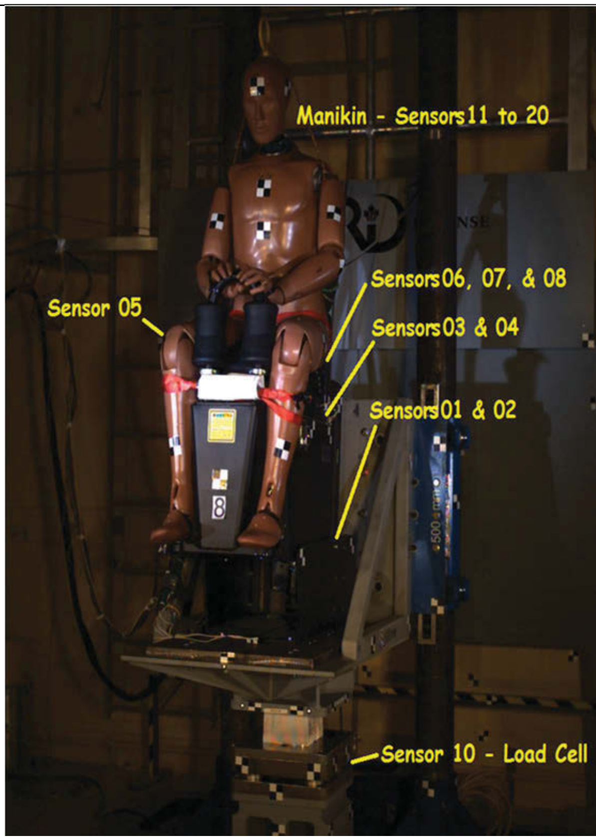
4. Table 3 describes the sensors and their locations when the ATD was installed on seat.

Table 3 – Sensors Location when ATD was installed on the Seats

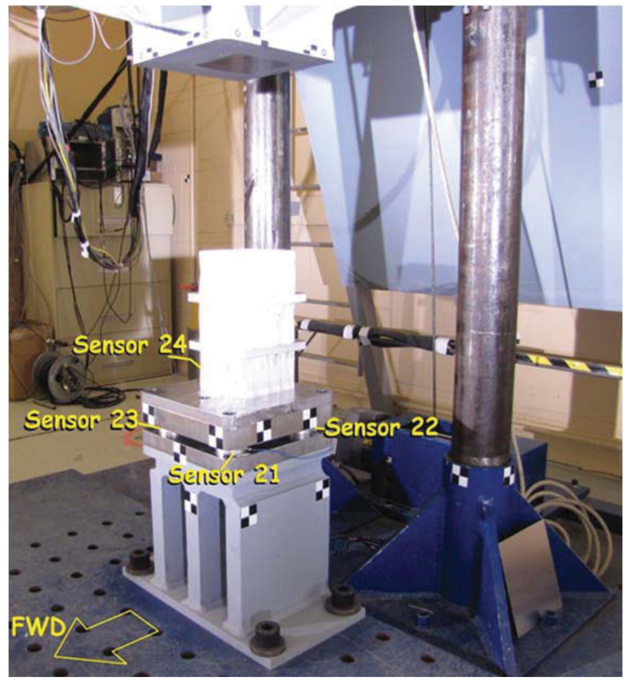
Description	Axis*	Numbering	Type	Model	Technical Support
Seat Base Acceleration	A_Z	Sensor 01	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 02	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Pan Acceleration	A_Z	Sensor 03	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 04	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Platform Acceleration	A_Z	Sensor 05	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Cushion Acceleration	A_Z	Sensor 06	IEPE Accelerometer	B&K 4515-B-002	NETE
	A_X	Sensor 07	IEPE Accelerometer	B&K 4515-B-002	NETE
	A_Y	Sensor 08	IEPE Accelerometer	B&K 4515-B-002	NETE
Impactor Force	F_Z	Sensor 10	Load Cell (Total)	PCB 207C	METC
	F_{Z1}	Sensor 21	Load Cell N^{o}1 – Front Left	PCB 207C	METC
	F_{Z2}	Sensor 22	Load Cell N^{o}2 – Back Left	PCB 207C	METC
	F_{Z3}	Sensor 23	Load Cell N^{o}3 – Front Right	PCB 207C	METC
	F_{Z4}	Sensor 24	Load Cell N^{o}4 – Back Right	PCB 207C	METC
ATD Pelvis Acceleration	A_Z	Sensor 11	Accelerometer	Endevco 7264D	METC
	A_X	Sensor 12	Accelerometer	Endevco 7264D	METC
ATD Chest Acceleration	A_Z	Sensor 13	Accelerometer	Endevco 7264D	METC
	A_X	Sensor 14	Accelerometer	Endevco 7264D	METC
ATD Lumbar Force	F_Z	Sensor 15	Load Cell	Denton 4609	METC
	F_X	Sensor 16	Load Cell	Denton 4609	METC
	M_Y	Sensor 17	Load Cell	Denton 4609	METC
ATD Neck Force & Moment	F_Z	Sensor 18	Load Cell	Denton 1716	METC
	F_X	Sensor 19	Load Cell	Denton 1716	METC
	M_Y	Sensor 20	Load Cell	Denton 1716	METC

* Axis Direction: Z = Vertical; X = Front to Back; Y = Side to Side.

5. Figure 1 shows a general overview of the sensors location when the ATD was installed on the seats.



(a) General Sensors location



(b) Load Cell – Sensor 10
(Sensors 21 + 22 + 23 + 24)

Figure 1 – Overview of Sensors Location when ATD is installed on the Seats

TESTING OF SHOCK MITIGATING SEATS

PHASE 2 – SHOCKWAVE + SHOXS + ULLMAN SEATS

TEST SEQUENCE FOR – PHASE 2 – DROP 01 TO 37 – May 2013

1. For the Phase 2 tests the following seats were tested:

   Shockwave Jockey Pod Seat (same as Phase 1);

   SHOXS 5500 Jockey Pod Seat; and

   Ullman Jockey Compact

2. The weights of the various "as tested" components are shown in Table 1.

Table 1 – Component Weights

Item	Weight (kg)							
	Shockwave		SHOXS			Ullman		
Carriage	440							
NETE Base Plate	93.5							
Ballast (on Carriage)	-		20			32		
Ballast (on Seat)	-	116	-	81.8	116	-	81.8	116
ATD – 50th Percentile Male	78.2	-	78.2	-	-	78.2	-	-
Seat – Fixed Portion	35.9		23.3			13		
Seat – Suspended Portion	14.5	10.9 (no cushion)	12.7	9.7 (no cushion)		7	2 (no cushion)	
Total	662.1	696.3	667.7	668.3	702.5	663.7	662.3	696.5

3. Table 2 describes the Phase 2 test sequence performed at DRDC Valcartier during May 2013. Twenty three configurations were tested using 37 drops from three drop heights.

3.1 SHOCKWAVE JOCKEY POD SEAT

   a. The first test condition drops performed with the 50th percentile ATD on the Shockwave Seat were Conditions A, B, U, V & W.

   b. The second test condition drops performed on Shockwave Seat with the seat cushion removed and a 116 kg rigid ballast added to the seat pan were Conditions C, D & E.

3.2 SHOXS JOCKEY SEAT

a. The third test condition drops performed with the ATD on the SHOXS Seat were Conditions F, G, & H.

b. The fourth test condition drops performed on the SHOXS seat with the cushion removed and a 81.8 kg rigid ballast added to the seat pan were Conditions I, J & K.

c. The fifth test condition drops performed on the SHOXS seat with the cushion removed and a 116 kg rigid ballast added to the seat pan were Conditions L & M.

3.3 ULLMAN SEAT

a. The sixth test condition drops performed with the ATD on the ULLMAN Seat were Conditions N, O, & P.

b. The seventh test condition drops performed on the Ullman seat with the cushion removed and a 81.8 kg rigid ballast added to the seat pan were Conditions Q & R.

c. The eighth test condition drops performed on the Ullman seat with the cushion removed and a116 kg rigid ballast added to the seat pan were Conditions S & T.

Table 2 – Test Sequence and Configurations

Test ID	Impactor Material	Impactor Area	Impactor Thickness
Condition A	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **ATD + Shockwave Seat**		
Drop T2-01	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition B	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m** **ATD + Shockwave Seat**		
Drop T2- 02	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Condition C	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **Rigid Ballast (116 kg) on Shockwave Seat**		
Drop T2- 03	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition D	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **Rigid Ballast (116 kg) on Shockwave Seat**		
Drop T2-04	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition E	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m** **Rigid Ballast (116 kg) on Shockwave Seat**		
Drop T2-05	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Condition F	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **ATD + SHOXS Seat**		
Drop T2-06	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T2-07	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition G	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **ATD + SHOXS Seat**		
Drop T2-08	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T2-09	4.5 pcf	0.0292 m^2	2 x 101.6 mm
*__Drop T2-10__	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition H	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m** **ATD + SHOXS Seat**		
Drop T2-11	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Drop T2-12	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Condition I	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **Rigid Ballast (81.8 kg) on SHOXS Seat**		
Drop T2-13	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T2-14	4.5 pcf	0.0292 m^2	1 x 101.6 mm

* Shot 10 was performed without the back cushion of the SHOXS seat (Ref. Figure 5)

Table 2 – Test Sequence and Configurations (Cont.)

Test ID	Impactor Material	Impactor Area	Impactor Thickness
Condition J	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **Rigid Ballast (81.8 kg) on SHOXS Seat**		
Drop T2-15	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T2-16	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition K	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m** **Rigid Ballast (81.8 kg) on SHOXS Seat**		
Drop T2-17	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T2-18	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition L	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **Rigid Ballast (116 kg) on SHOXS Seat**		
Drop T2-19	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition M	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **Rigid Ballast (116 kg) on SHOXS Seat**		
Drop T2-20	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition N	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **ATD + ULLMAN Seat**		
Drop T2-21	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T2-22	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition O	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **ATD + ULLMAN Seat**		
Drop T2-23	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Shot 24	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition P	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m** **ATD + ULLMAN Seat**		
Drop T2-25	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T2-26	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition Q	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **Rigid Ballast (81.8 kg) on ULLMAN Seat**		
Drop T2-27	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T2-28	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition R	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **Rigid Ballast (81.8 kg) on ULLMAN Seat**		
Drop T2-29	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop T2-30	4.5 pcf	0.0292 m^2	2 x 101.6 mm

Table 2 – Test Sequence and Configurations (Cont.)

Test ID	Impactor Material	Impactor Area	Impactor Thickness
Condition S	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **Rigid Ballast (116 kg) on ULLMAN Seat**		
Drop T2-31	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition T	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **Rigid Ballast (116 kg) on ULLMAN Seat**		
Drop T2-32	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition U	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m** **ATD + Shockwave Seat**		
Drop T2-33	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T2-34	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop T2-35	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition V	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **ATD + Shockwave Seat**		
Drop T2-36	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Condition W	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m** **ATD + Shockwave Seat**		
Drop T2-37	4.5 pcf	0.0292 m^2	3 x 101.6 mm

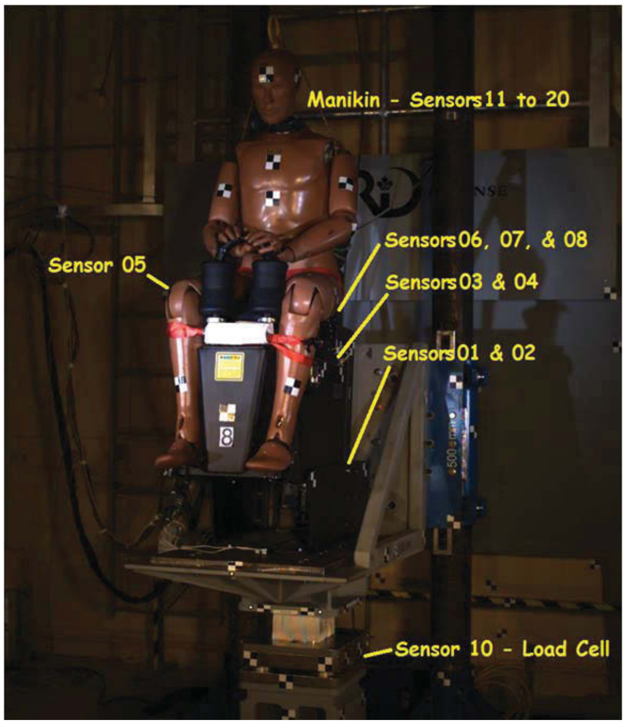
4. Table 3 details the type of sensors used and their locations when testing with the ATD Installed.

Table 3 – Sensors Types and Installed Locations

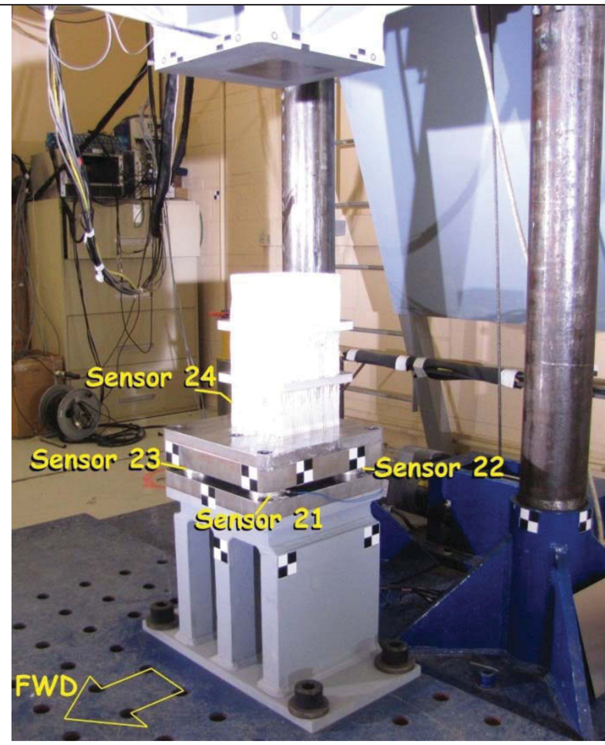
Description	Axis*	Number	Type	Model	Technical Support
Platform Acceleration	A_Z	Sensor 01	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 02	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Pan Acceleration	A_Z	Sensor 03	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 04	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Pan Acceleration	A_Z	Sensor 05	Piezo-Resistive Accelerometer	Endevco 7264D	NETE
Seat Cushion Acceleration	A_Z	Sensor 06	IEPE Accelerometer	B&K 4515-B-002	NETE
	A_X	Sensor 07	IEPE Accelerometer	B&K 4515-B-002	NETE
	A_Y	Sensor 08	IEPE Accelerometer	B&K 4515-B-002	NETE
Impactor Force	F_Z	Sensor 10	Load Cell (Total)	PCB 207C	METC
	F_{Z1}	Sensor 21	Load Cell N^{o}1 – Front Left	PCB 207C	METC
	F_{Z2}	Sensor 22	Load Cell N^{o}2 – Back Left	PCB 207C	METC
	F_{Z3}	Sensor 23	Load Cell N^{o}3 – Front Right	PCB 207C	METC
	F_{Z4}	Sensor 24	Load Cell N^{o}4 – Back Right	PCB 207C	METC
ATD Pelvis Acceleration	A_Z	Sensor 11	Accelerometer	Endevco 7264D	METC
	A_X	Sensor 12	Accelerometer	Endevco 7264D	METC
ATD Chest Acceleration	A_Z	Sensor 13	Accelerometer	Endevco 7264D	METC
	A_X	Sensor 14	Accelerometer	Endevco 7264D	METC
ATD Lumbar Force & Moment	F_Z	Sensor 15	Load Cell	Denton 4609	METC
	F_X	Sensor 16	Load Cell	Denton 4609	METC
	M_Y	Sensor 17	Load Cell	Denton 4609	METC
ATD Neck Force & Moment	F_Z	Sensor 18	Load Cell	Denton 1716	METC
	F_X	Sensor 19	Load Cell	Denton 1716	METC
	M_Y	Sensor 20	Load Cell	Denton 1716	METC

* Axis Direction: *Z* = Vertical; *X* = Front to Back; *Y* = Side to Side.

5. Figure 1 shows a typical overall view of the sensors location when the ATD was installed on the seats.



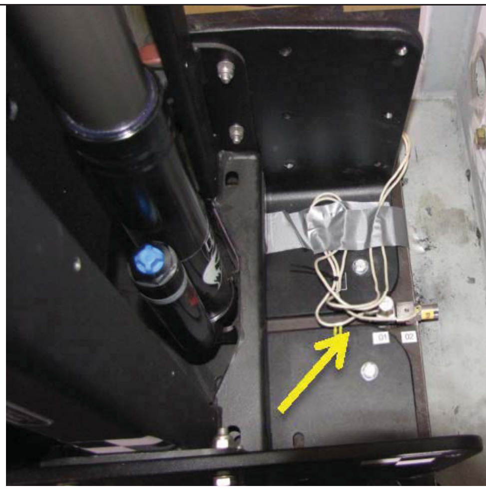
(a) Typical Sensors Locations



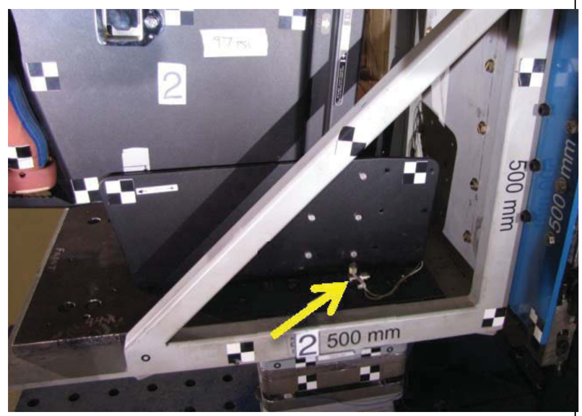
(b) Load Cell – Sensor 10 = Sensors 21 + 22 + 23 + 24

Figure 1 – Overall View of Sensors Location when the ATD was installed on the Seats

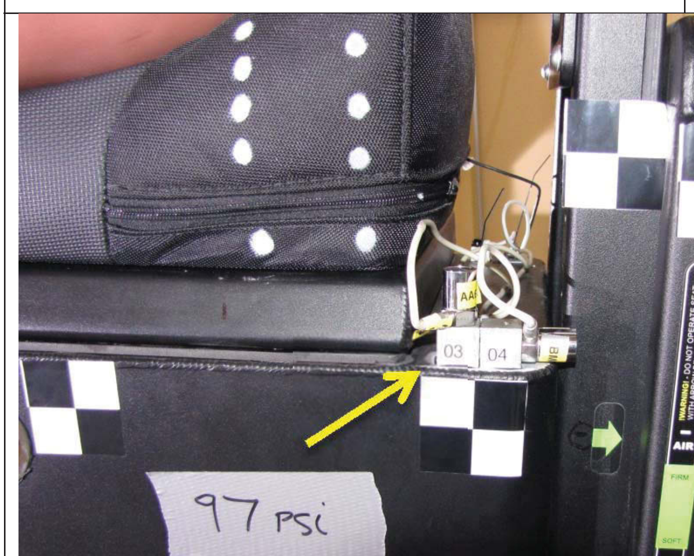
6. Figure 2 shows localised views of the NETE seat structure accelerometer locations when the ATD was installed on the Shockwave seat.



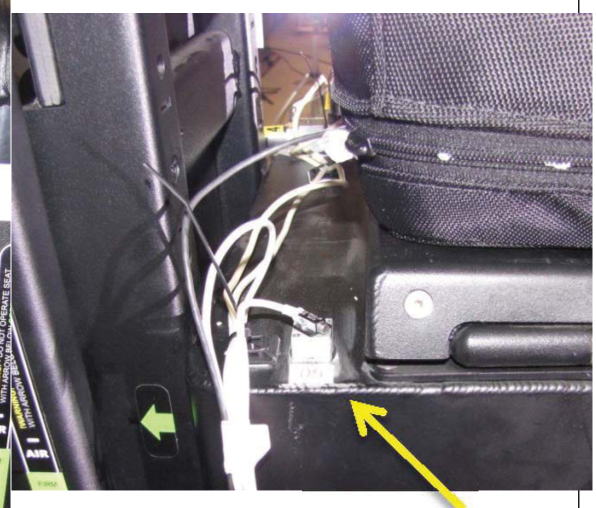
(a) Sensor 01 and Sensor 02 ⇨ for Conditions U, V &W



(b) Sensors 01 and 02 ⇨ for Conditions A, B, C, D, & E



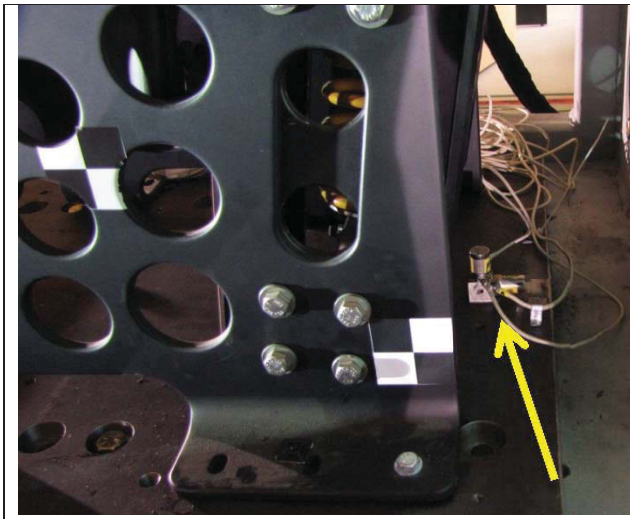
(c) Sensor 03 and Sensor 04



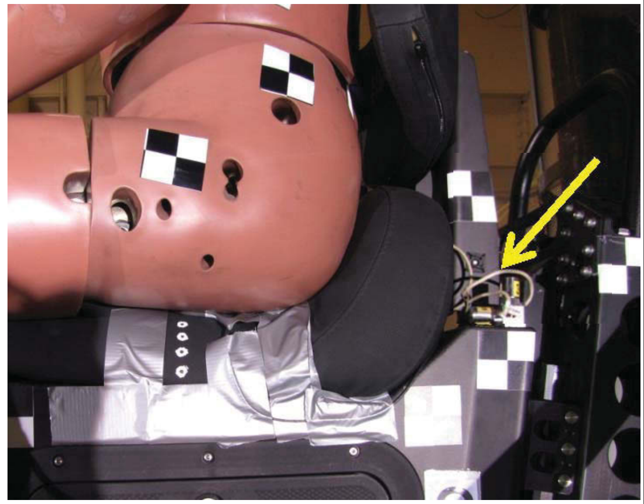
(c) Sensor 05

Figure 2 - Localised Views of Seat Structure Accelerometers Installed on the Shockwave Seat

7. Figure 3 shows localised views of the sensors locations when the ATD was installed on the SHOXS seat.



(a) Sensor 01 and Sensor 02

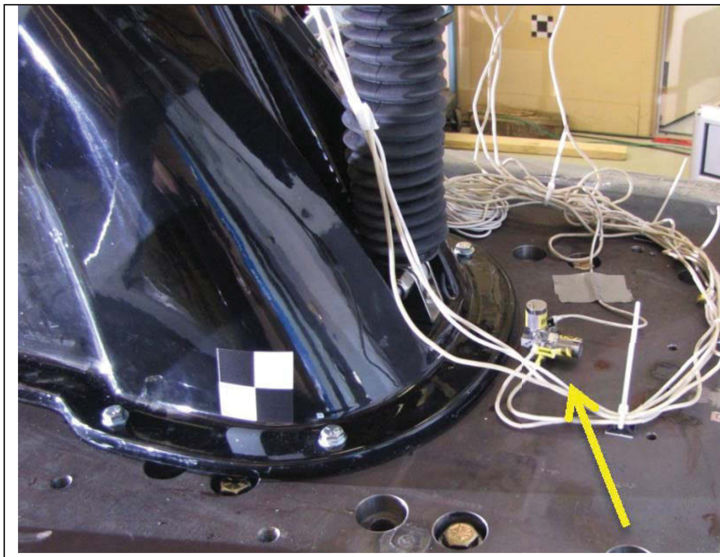


(b) Sensor 03 and Sensor 04

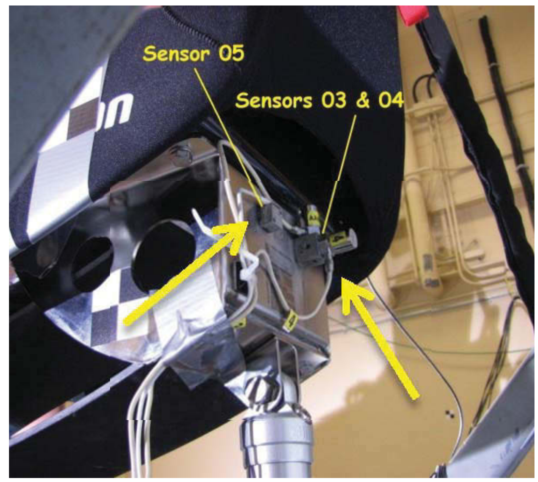
(c) Sensor 05

Figure 3 - Localised Views of Sensors Locations when ATD was installed on the SHOXS seat.

8. Figure 4 shows localised views of the sensors location when the ATD was installed on the Ullman seat.



(a) Sensor 01 and Sensor 02

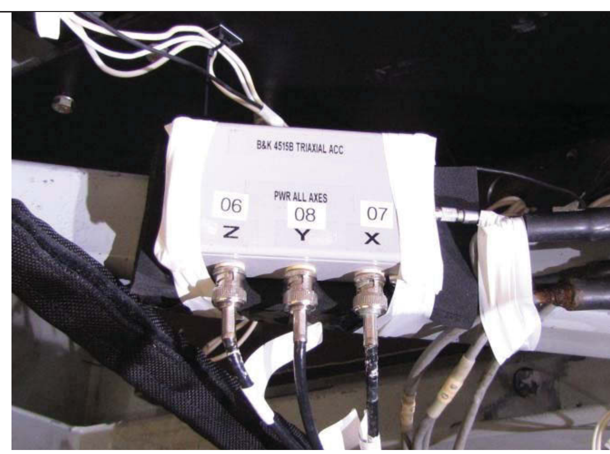


(b) Sensors 03, 04, & 05

Figure 4 - Localised Views of Sensors Location when ATD installed on the ULLMAN seat (Conditions F, G, & H)

9. Figure 5 shows the typical installation of the three-axis seat pad accelerometers and the sensor cable junction box..

(a) Typical Seat Pad Accelerometer Installation for Sensors 06, 07 & 08

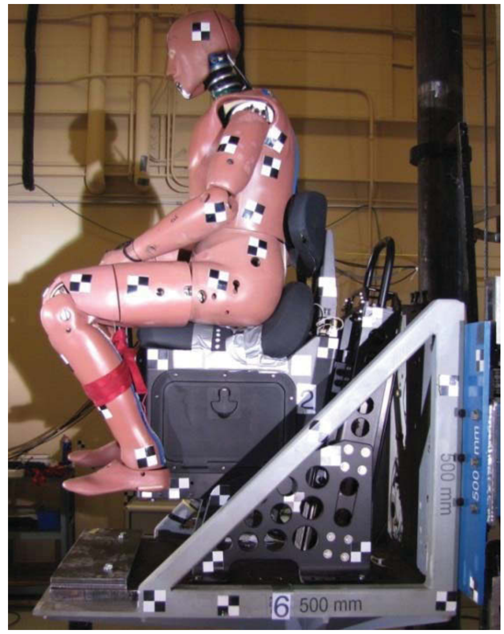


(b) Typical Seat Pad Accelerometer Junction Box Installation

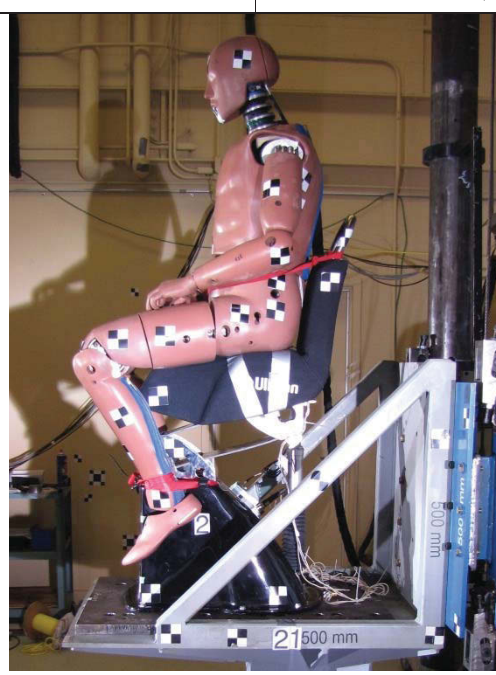
Figure 5 – Typical Seat Pad Accelerometers Installation

9. Figure 6 shows each of the seats with the ATD installed.

(a) Shockwave Seat



(b) SHOXS Seat



(c) Ullman Seat

Figure 6 – Shows each seat with the ATD installed

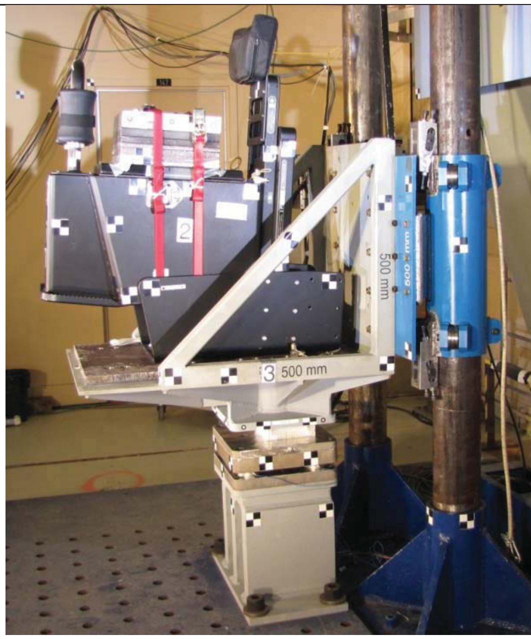
10. Table 4 details the type of sensors and their locations when the rigid ballast is installed on the seats.

Table 4 – Sensor Location when rigid ballast is installed.

Description	Axis*	Number	Type	Model	Technical Support
Platform Acceleration	A_Z	Sensor 01	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 02	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Pan Acceleration	A_Z	Sensor 03	Piezo-Resistive Accelerometer	Endevco 2262	NETE
	A_X	Sensor 04	Piezo-Resistive Accelerometer	Endevco 2262	NETE
Seat Pan Acceleration (on Rigid Ballast)	A_Z	Sensor 05	Piezo-Resistive Accelerometer	Endevco 7264D	NETE
Impactor Force	F_Z	Sensor 10	Load Cell (Total)	PCB 207C	METC
	F_{Z1}	Sensor 21	Load Cell N°1 – Front Left	PCB 207C	METC
	F_{Z2}	Sensor 22	Load Cell N°2 – Back Left	PCB 207C	METC
	F_{Z3}	Sensor 23	Load Cell N°3 – Front Right	PCB 207C	METC
	F_{Z4}	Sensor 24	Load Cell N°4 – Back Right	PCB 207C	METC

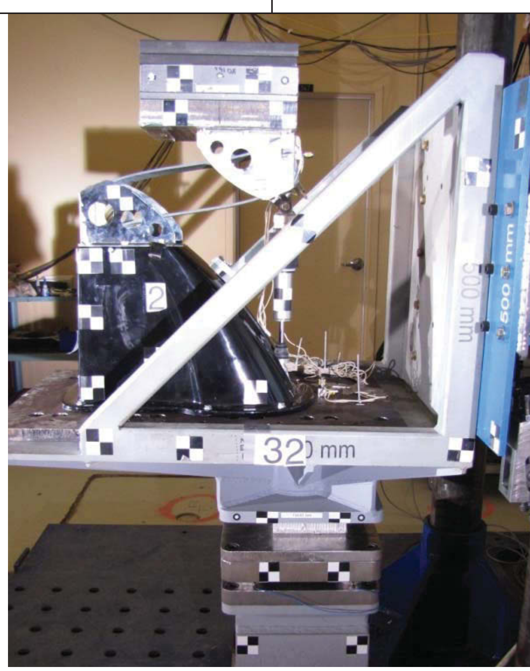
* Axis Direction: *Z* = Vertical; *X* = Front to Back; *Y* = Side to Side.

11. Figure 7 shows the views of each seat setup when both rigid ballast weights are installed.



(a) Shockwave Seat with Rigid Ballast Installed

(b) SHOXS Seat with Rigid Ballast Installed



(c) Ullman Seat with Rigid Ballast Installed

Figure 7 – Views of Seat Set-up when Rigid Ballasts are Installed

TESTING OF SHOCK MITIGATING SEATS

PHASE 3 – ZODIAC + SHOCKWAVE + SHOXS SEATS

TEST SEQUENCE FOR – PHASE 3 – DROP 01 TO 21 – DECEMBER 2013

1. For the Phase 3 tests; three types of seat were tested:

   Shockwave Jockey Pod Seat;

   Zodiac Jockey Seat; and

   SHOXS 5500 Jockey Pod Seat.

2. Table 1 details the weights of the various components as tested.

Item	Weight (kg)		
	Shockwave	Zodiac	SHOXS
Carriage	440		
NETE Base Plate	93.5		
NETE Interface Plate	39.4		
ATD – 50^{th} Percentile Male	78.2		
Seat – Fixed Portion	17.3	11.1	13.7
Seat – Suspended Portion	14.5	11.8	12.7
Total	682.9	674.0	677.5

3. Table 2 describes the Phase 3 test sequence performed on the seats at DRDC Valcartier during December 2013. There were eleven main conditions that were completed:

3.1 SHOCKWAVE SEAT

The main conditions performed with the 50^{th} percentile ATD on the Shockwave Seat were Conditions A, B, C & D.

3.2 ZODIAC SEAT

The main conditions performed with the 50^{th} percentile ATD on the Zodiac Seat were Conditions E, F, G and H.

3.3 SHOXS SEAT

The main conditions were performed with the 50^{th} percentile ATD on the SHOXS Seat were Conditions I, J & K.

Table 2 – Test Sequence and Configurations

Test ID	Impactor Material	Impactor Area	Impactor Thickness
Condition A	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m Shockwave Seat + ATD (Pressure 67 psi)**		
Drop 3-01	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Condition B	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m Shockwave Seat + ATD (Pressure 97 psi)**		
Drop 3-02	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop 3-03			
Condition C	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m Shockwave Seat + ATD (Pressure 97 psi)**		
Drop 3-04	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop 3-05			
Drop 3-06			
Condition D	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m Shockwave Seat + ATD (Pressure 97 psi)**		
Drop 3-07	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Drop 3-08			
Condition E	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m Zodiac Seat + ATD (Pressure 66 psi)**		
Drop 3-09	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop 3-10			
Condition F	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m Zodiac Seat + ATD (Pressure 66 psi)**		
Drop 3-11	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop 3-12			
Condition G	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m Zodiac Seat + ATD (Pressure 67 psi)**		
Drop 3-13	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Drop 3-14			
Condition H	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m Zodiac Seat + ATD (Pressure 97 psi)**		
Drop 3-15	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Condition I	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m SHOXS Seat + ATD 80 psi pressure**		
Drop 3-16	4.5 pcf	0.0292 m^2	1 x 101.6 mm
Drop 3-17			

Table 2 (Cont.) – Test Sequence and Configurations

Test ID	Impactor Material	Impactor Area	Impactor Thickness
Condition J	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m SHOXS Seat + ATD (Pressure 80 psi)**		
Drop 3-18	4.5 pcf	0.0292 m^2	2 x 101.6 mm
Drop 3-19			
Condition K	**Targeted ΔV = 6.5 m/s – Drop Height ≅ 2.931 m SHOXS Seat + ATD**		
Drop 3-20	4.5 pcf	0.0292 m^2	3 x 101.6 mm
Drop 3-21			

4. Table 3 and 4 detail the sensors and their locations when the ATD was installed on seats.

Table 3 – NETE Sensors Location when the ATD is installed on the Seats

Description	Axis*	Numbering	Type	Model
Seat Base Acceleration	A_Z	Sensor 01	Piezo-Resistive Accelerometer	Endevco 2262
	A_X	Sensor 02	Piezo-Resistive Accelerometer	Endevco 2262
Seat Pan Acceleration	A_Z	Sensor 03	Piezo-Resistive Accelerometer	Endevco 2262
	A_X	Sensor 04	Piezo-Resistive Accelerometer	Endevco 2262
Platform Acceleration	A_Z	Sensor 05	Piezo-Resistive Accelerometer	Endevco 2262
Seat Cushion Acceleration	A_Z	Sensor 06	IEPE Accelerometer	B&K 4515-B-002
	A_X	Sensor 07	IEPE Accelerometer	B&K 4515-B-002
	A_Y	Sensor 08	IEPE Accelerometer	B&K 4515-B-002

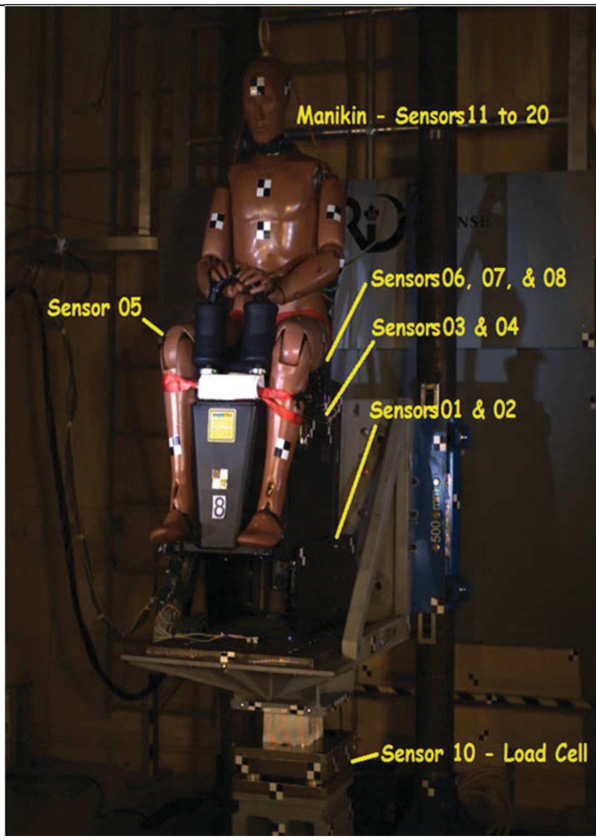
* Axis Direction: *Z* = Vertical; *X* = Front to Back; *Y* = Side to Side.

Table 4 – METC Sensor Locations when the ATD is installed on the seats

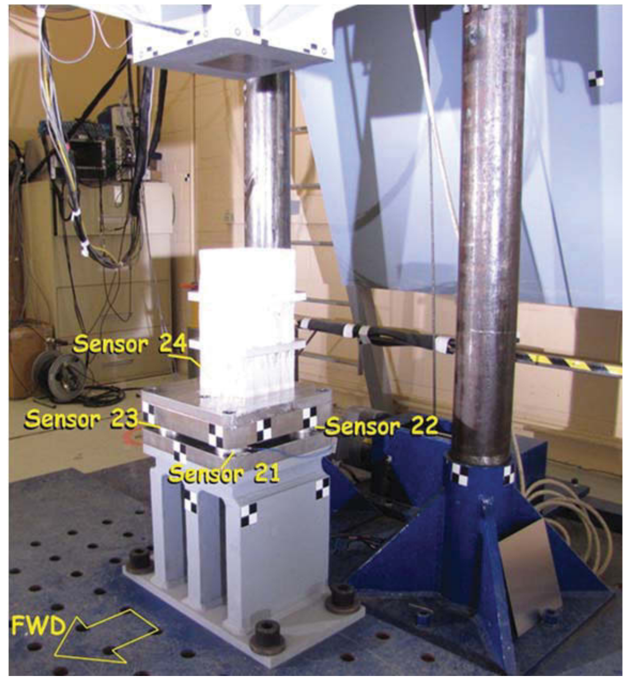
Description	Axis*	Numbering	Type	Model
Impactor Force	F_Z	Sensor 10	Load Cell (Total)	PCB 207C
	F_{Z1}	Sensor 21	Load Cell N^{o}1 – Front Left	PCB 207C
	F_{Z2}	Sensor 22	Load Cell N^{o}2 – Back Left	PCB 207C
	F_{Z3}	Sensor 23	Load Cell N^{o}3 – Front Right	PCB 207C
	F_{Z4}	Sensor 24	Load Cell N^{o}4 – Back Right	PCB 207C
ATD Pelvis Acceleration	A_Z	Sensor 11	Accelerometer	Endevco 7264D
	A_X	Sensor 12	Accelerometer	Endevco 7264D
ATD Chest Acceleration	A_Z	Sensor 13	Accelerometer	Endevco 7264D
	A_X	Sensor 14	Accelerometer	Endevco 7264D
ATD Lumbar Force	F_Z	Sensor 15	Load Cell	Denton 4609
	F_X	Sensor 16	Load Cell	Denton 4609
	M_Y	Sensor 17	Load Cell	Denton 4609
ATD Neck Force & Moment	F_Z	Sensor 18	Load Cell	Denton 1716
	F_X	Sensor 19	Load Cell	Denton 1716
	M_Y	Sensor 20	Load Cell	Denton 1716

* Axis Direction: Z = Vertical; X = Front to Back; Y = Side to Side.

5. Figure 1 shows a general overview of the sensors location when the ATD was installed on the seats.



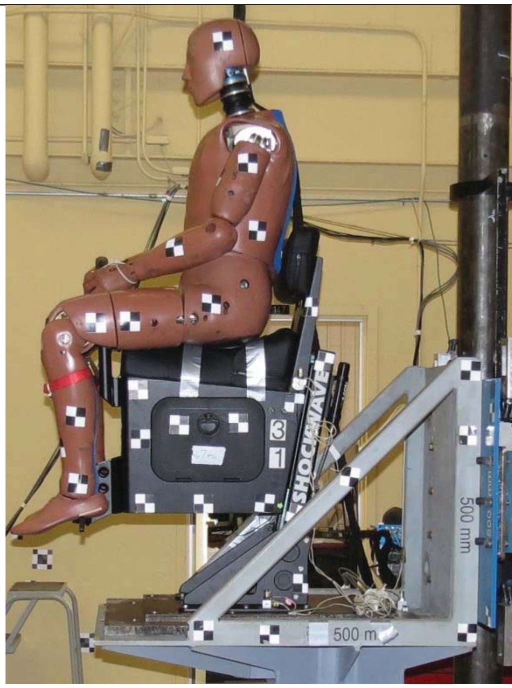
(a) General Sensors location



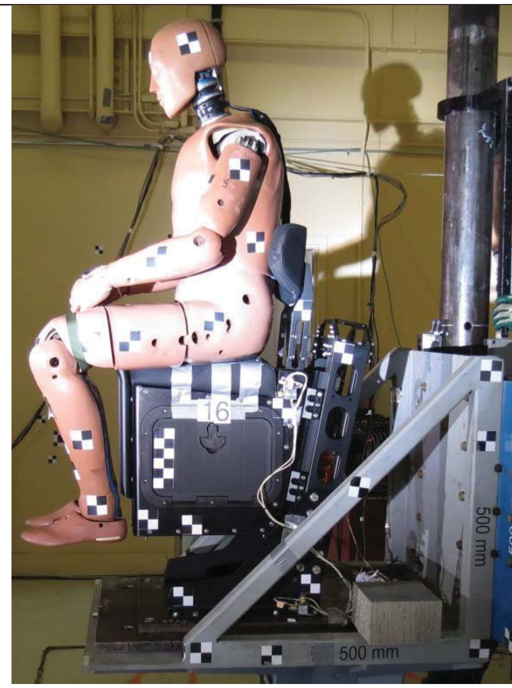
(b) Load Cell – Sensor 10
(Sensors 21 + 22 + 23 + 24)

Figure 1 – Overview of Sensors Location when ATD is installed on the Seats

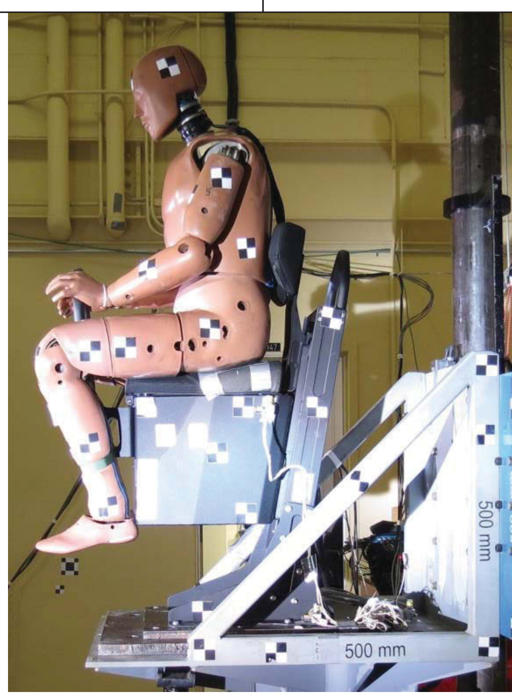
9. Figure 2 shows each of the seats with the ATD installed.



(a) Shockwave Seat



(b) SHOXS Seat



(c) Zodiac Seat

Figure 2 – Each Seat with the ATD Installed

TESTING OF SHOCK MITIGATING SEATS

PHASE 4 – SHOXS + ZODIAC + SHOCKWAVE SEATS

TEST SEQUENCE FOR – PHASE 4 – DROP 01 TO 23 – January 2014

1. For the Phase 4 tests; three types of seat were tested:

   Shockwave Jockey Pod Seat;

   Zodiac Jockey Seat; and

   SHOXS 5500 Jockey Pod Seat.

2. The weights of the various components as tested are shown below in Table 1.

Table 1 – Test Component Weight

Item	Weight (kg)		
	Shockwave	Zodiac	SHOXS
Carriage	440		
NETE Base Plate	93.5		
NETE Interface Plate	39.4		
ATD – 50th Percentile Male	78.2		
Seat – Fixed Portion	13.7	11.1	17.3
Seat – Suspended Portion	12.7	11.8	14.5
Total	677.5	674.0	682.9

3. Table 2 describes the Phase 4 test sequence performed on the seats at DRDC Valcartier during January 2014. Seven test conditions that were completed and all included the use of a 50th percentile anthropomorphic test ATD.

3.1 SHOXS SEAT - The main conditions performed with the SHOXS Seat were Conditions A, B & C. Condition A was used to confirm that the impactor area was delivering the required deceleration. The measured deceleration was greater than required and the impactor area was reduced to suit for the remaining test conditions.

3.2 ZODIAC SEAT - The main conditions performed with the Zodiac Seat were Conditions D & E.

3.3 SHOCKWAVE SEAT - The main conditions were performed with the Shockwave Seat were Conditions F & G.

Table 2 – Test Sequence and Configurations

Test ID	Impactor Material Density (lb/ft^3)	Impactor Area (m^2)	Impactor Thickness (mm)
Condition A	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.834 m SHOXS Seat + ATD (80 psi pressure)**		
Drop T4-01	1.6	0.0968	2 x 101.6
Condition B	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.834 m SHOXS Seat + ATD (80 psi pressure)**		
Drop T4-02	1.6	0.0691	2 x 101.6
Drop T4-03			
Drop T4-04			
Condition C	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m SHOXS Seat + ATD (80 psi pressure)**		
Drop T4-05	1.6	0.0691	4 x 101.6
Drop T4-06			
Drop T4-07			
Condition D	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m Zodiac Seat + ATD (Pressure 68 psi)**		
Drop T4-08	1.6	0.0691	2 x 101.6
Drop T4-09			
Drop T4-10			
Drop T4-11			
Drop T4-12			
Condition E	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m Zodiac Seat + ATD (Pressure 68 psi)**		
Drop T4-13	1.6	0.0691	4 x 101.6
Drop T4-14			
Drop T4-15			
Drop T4-16			

Test ID	Impactor Material Density (lb/ft^3)	Impactor Area (m^2)	Impactor Thickness (mm)
Condition F	**Targeted ΔV = 2.5 m/s – Drop Height ≅ 0.836 m**		
Drop T4-17	1.6	0.0691	2 x 101.6
Drop T4-18			
Drop T4-19			
Drop T4-20			
Condition G	**Targeted ΔV = 4.5 m/s – Drop Height ≅ 1.735 m** **Shockwave Seat + ATD (97 psi pressure)**		
Drop T4-21	1.6	0.0691	4 x 101.6 mm
Drop T4-22			
Drop T4-23			

4. Table 3 and 4 detail the sensors and their locations when the ATD was installed on a seat.

Table 3 – NETE Sensors Location when ATD installed on the Seats

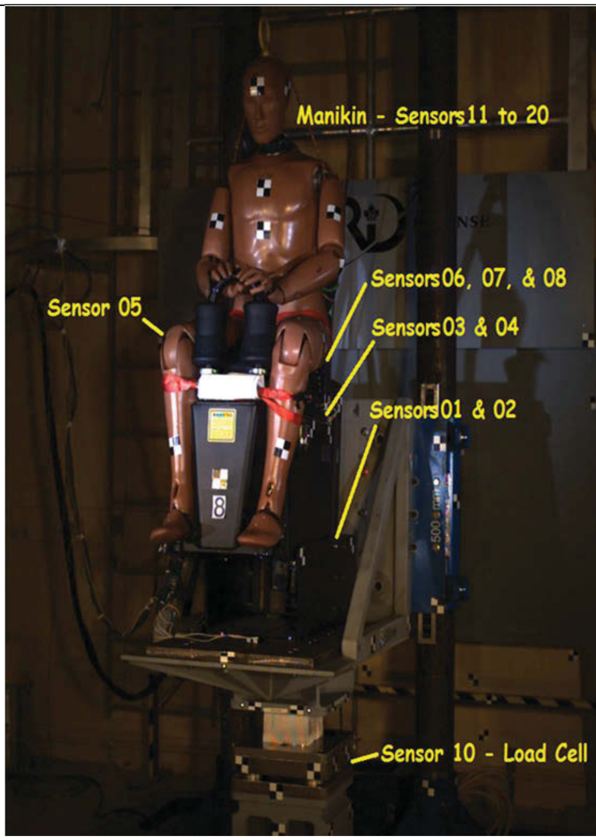
Description	ID & Axis*	Numbering	Type	Model
Seat Base Acceleration	A_Z	Sensor 01	Piezo-Resistive Accelerometer	Endevco 2262
	A_X	Sensor 02	Piezo-Resistive Accelerometer	Endevco 2262
Seat Pan Acceleration	A_Z	Sensor 03	Piezo-Resistive Accelerometer	Endevco 2262
	A_X	Sensor 04	Piezo-Resistive Accelerometer	Endevco 2262
Platform Acceleration	A_Z	Sensor 05	Piezo-Resistive Accelerometer	Endevco 2262
Seat Cushion Acceleration	A_Z	Sensor 06	IEPE Accelerometer	B&K 4515-B-002
	A_X	Sensor 07	IEPE Accelerometer	B&K 4515-B-002
	A_Y	Sensor 08	IEPE Accelerometer	B&K 4515-B-002

Table 4 – METC Sensors Location when ATD installed on the Seats

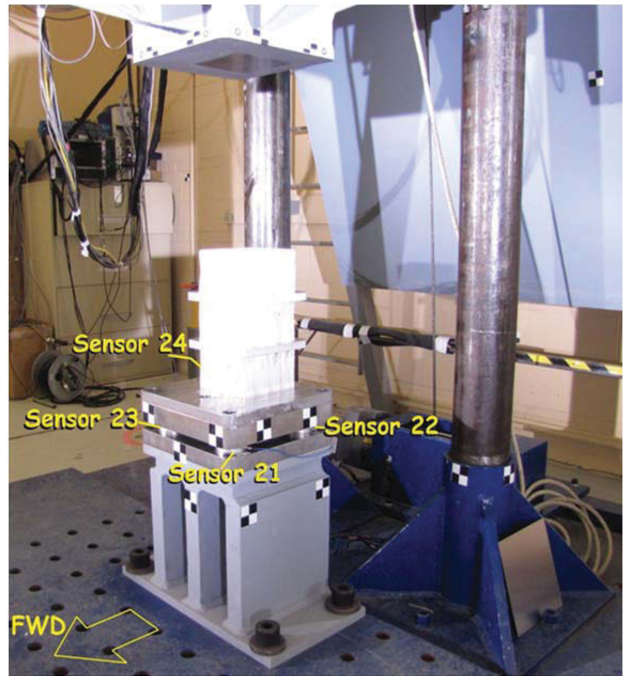
Description	ID & Axis*	Numbering	Type	Model
Platform Acceleration	A_Z	N/A	Accelerometer	Endevco 7264D
Impactor Force	F_Z	Sensor 10	Load Cell (Total)	PCB 207C
	F_{Z1}	Sensor 21	Load Cell N°1 – Front Left	PCB 207C
	F_{Z2}	Sensor 22	Load Cell N°2 – Back Left	PCB 207C
	F_{Z3}	Sensor 23	Load Cell N°3 – Front Right	PCB 207C
	F_{Z4}	Sensor 24	Load Cell N°4 – Back Right	PCB 207C
ATD Pelvis Acceleration	A_Z	Sensor 11	Accelerometer	Endevco 7264D
	A_X	Sensor 12	Accelerometer	Endevco 7264D
ATD Chest Acceleration	A_Z	Sensor 13	Accelerometer	Endevco 7264D
	A_X	Sensor 14	Accelerometer	Endevco 7264D
ATD Lumbar Force	F_Z	Sensor 15	Load Cell	Denton 4609
	F_X	Sensor 16	Load Cell	Denton 4609
	M_Y	Sensor 17	Load Cell	Denton 4609
ATD Neck Force & Moment	F_Z	Sensor 18	Load Cell	Denton 1716
	F_X	Sensor 19	Load Cell	Denton 1716
	M_Y	Sensor 20	Load Cell	Denton 1716

* Axis Direction: Z = Vertical; X = Front to Back; Y = Side to Side.

5. Figure 1 shows a general overview of the sensors location when the ATD was installed on the seats.



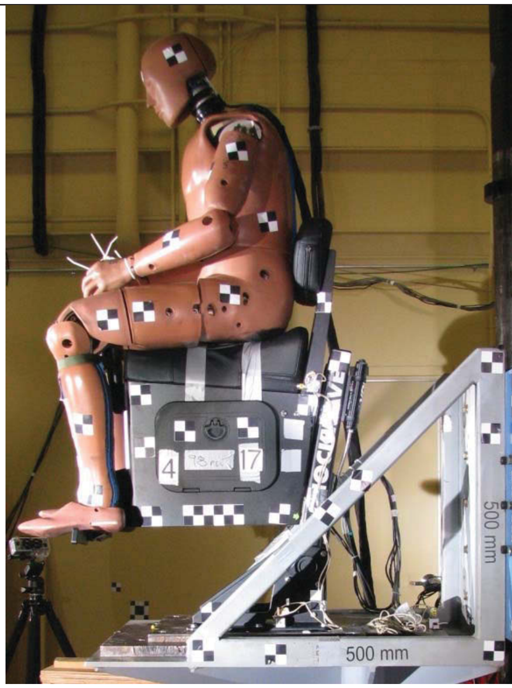
(a) General Sensors location



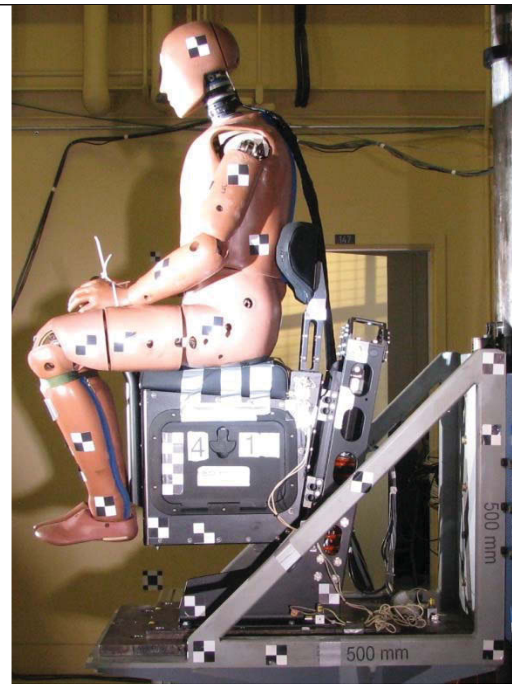
(b) Load Cell – Sensor 10
(Sensors 21 + 22 + 23 + 24)

Figure 1 – Overview of Sensors Location when ATD is installed on the Seats

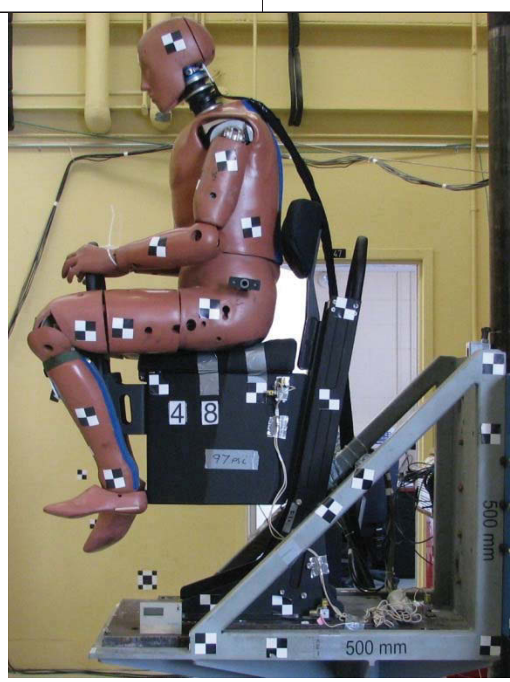
9. Figure 2 shows each of the seats with the ATD installed.



(a) Shockwave Seat



(b) SHOXS Seat



(c) Zodiac Seat

Figure 2 – Shows each seat with the ATD installed

2711 (NETE CS) ZT4110-R
23 April 2014

NOTICE

This documentation has been reviewed by the technical authority and does not contain controlled goods.

AVIS

Cette documentation a été révisée par l'Autorité technique et ne contient pas de marchandises contrôlées.